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Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
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Journal of Sedimentary Petrology

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Articles submitted for publication to the JOURNAL OF SEDIMENTARY PETROLOGY should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 7, NO. 2, PP. 41–50, FIGS. 1–4, AUGUST, 1937

MARINE SEDIMENTS AROUND CATALINA ISLAND[1,2]

F. P. SHEPARD AND W. F. WRATH
University of Illinois

ABSTRACT

The types of sediment found on the narrow shelves around Catalina show distinct relation to the nature of the environment as do also the topographic characters of the shelves. Thus the flat platform off the protected area around Avalon is covered largely with organic sediments presumably because of the absence of detrital material washed from the shore. On the other hand, the shelf on the exposed side slopes outward continuously and is covered with fine sediments which are interpreted as coming principally from the present day erosion of the shore cliffs. The zone northwest of Avalon, which lacks a notable shelf, suggests the absence of wave erosion because of its protected position. Extensive tracts of rocky bottom near the northwest end of the island are explained by the currents which impinge against this end and prevent deposition of fine debris. Currents are also given as part explanation of the coarse sediment, both detrital and organic, which was discovered in many places along the outer margin of the narrow shelves.

INTRODUCTION

The miniature shelves around Catalina Island off the coast of Southern California provide a remarkably fine opportunity to study sedimentation conditions. On the northeast side of the island the seas are so smooth that boats anchor all along the coast and are only disturbed on rare occasions by a "Santa Ana" which blows off the mainland so that boats must be moved to the other side of the island for protection. On the south and west sides of Catalina the large rollers from the open Pacific impinge against the coast and during storms break with great force against the sea cliffs. The northwestern point of the island has still different conditions since in addition to the open sweep of the ocean waves distinct currents are observable setting particularly from the northwest direction.

During the spring of 1934 the senior author collected sediments from the sea floor around Catalina while accompanying a vessel of the Coast and Geodetic Survey. Samples were obtained by small pipe dredges and in addition the tallow of the lead was examined after numerous vertical cast soundings in order to obtain indications of bottom character. The samples were analyzed by the junior author using standard sieves and pipetting for the smaller grades. In addition heavy mineral studies were made and examination of all the samples under binoculars was undertaken by both authors.

From the study of the samples and from the reports made by Coast Survey officers of bottom character around the island a map has been constructed to depict the distribution of sediments in the vicinity

[1] Called also Santa Catalina Island.

[2] Some of the technical aspects of the report are treated more fully in a master's thesis by the junior author, which is available at the Library of the University of Illinois.

(fig. 1). In addition, contour maps and profiles were made from the Coast and Geodetic Survey soundings (Figs. 2 and 3.) Figure 2 gives also the location of the samples which were studied.

RELATION OF SEDIMENTS TO WAVES AND CURRENTS

Organic material on sheltered side.—Examinations of the sediments makes it evident that the bottom character has definite relation to the wave and current conditions. The protected side of the island in the vicinity of Avalon revealed a shelf largely covered with organic sediments (fig. 1). On the other hand, the organic content on the exposed side of the island proved to be of small quantity. Unfortunately, the extent of the organic zone to the northwest along the northeast coast is not determinable at present, since no samples were procured from there and since the notations of bottom character by the Coast Survey parties do not distinguish between organic and inorganic sands. Off Avalon there appears to be little doubt but that the absence of sediment washed from the land accounts for the organic concentrate.

Northwest zones.—It is probably more than a coincidence that there should be more reports of rock bottom from the northwestern end of the island than elsewhere. These reports of rock bottom which come largely from Coast Survey work are based on the finding of fresh scars on the lead or from the obtaining of angular rock fragments. Where several reports of this sort come from the same general locality it seems highly probable that true ledge rock has been encountered. Accordingly, these rocky zones off the northwest end of the island indicate that the currents which impinge against this end of the island are preventing and have prevented the deposition of sediment in these zones. As still further indication of the effect of these currents we find the zone of coarse sand off the northwest point of the island. The finding of rock bottom at depths of well over 100 fathoms may also be of some significance. Certainly the waves could not produce this condition.

If Twenhofel's recent suggestions regarding marine conglomerates are correct (1), the south side of Catalina should be an ideal place for the transportation of gravel and coarse sand across the narrow, relatively steep shelf which adjoins the rocky coast. The waves certainly come in against this shore with at least as much force as would be expected for most coasts of the ancient epicontinental seas. It is of interest, therefore, to note that it is only along the coast and out to about 10 fathoms that even the coarse sand extends. All information available shows that the shelf beyond this depth is covered with fine sand or silty sand. It is only at the very margin of the shelves that coarsening of the sediment is observed.

The evidence gained from this observation is in line with other data obtained by the senior author from various continental shelves tending

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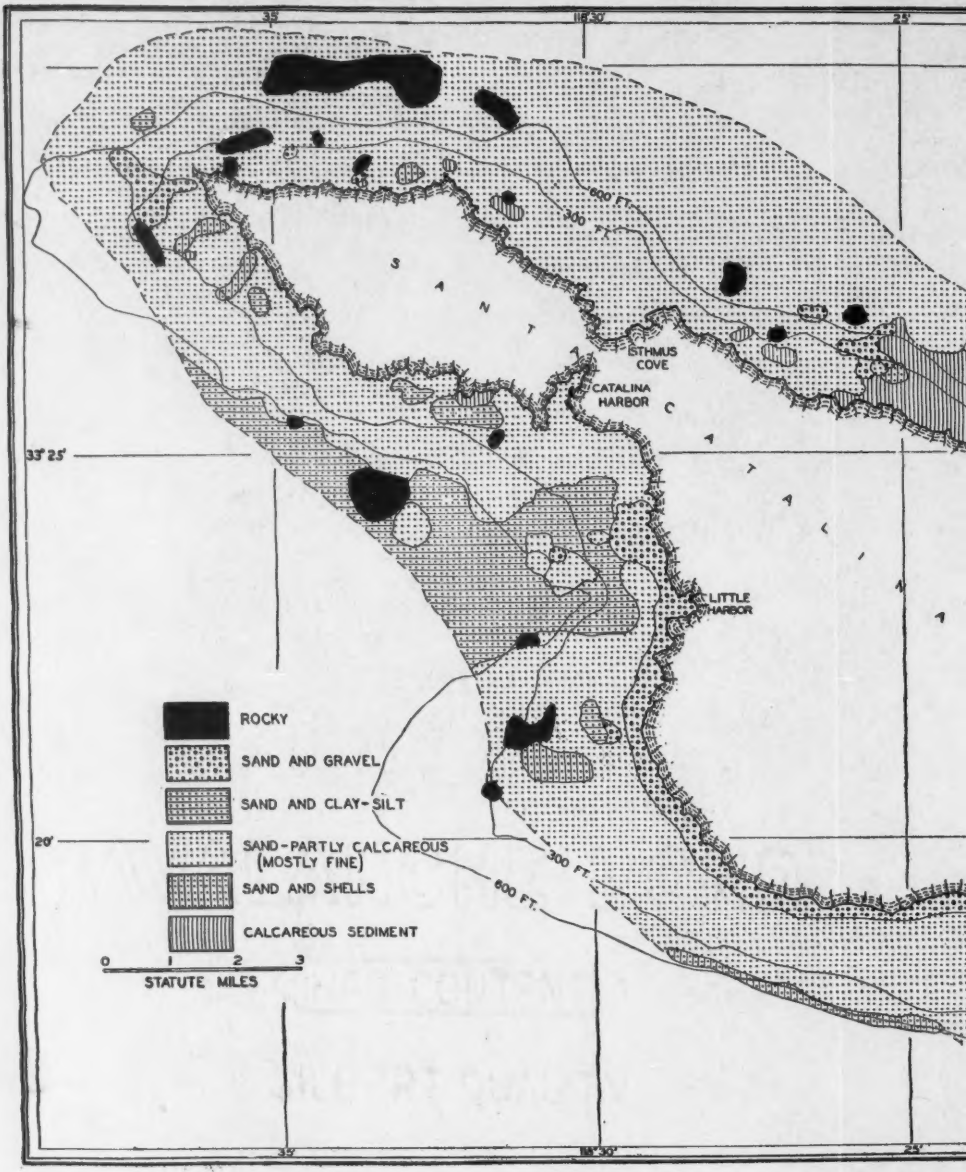
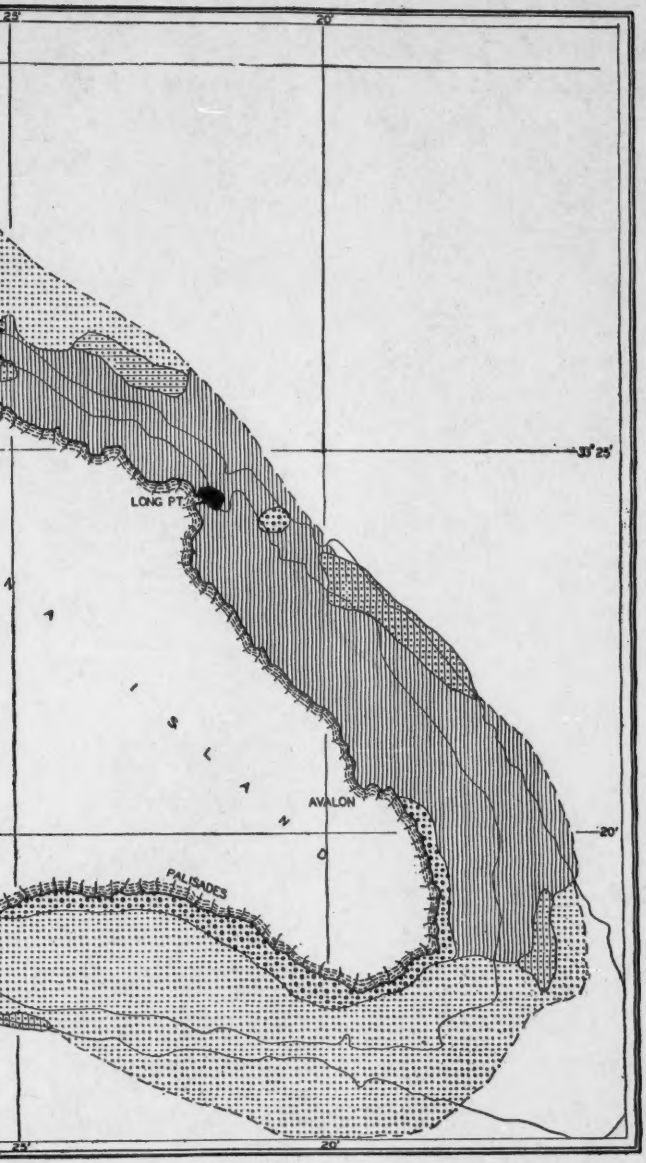


FIG. 1.—The general distribution of sediment types around the island. Much of the sand zone off t



zone off the northern portion of the island may be calcareous.

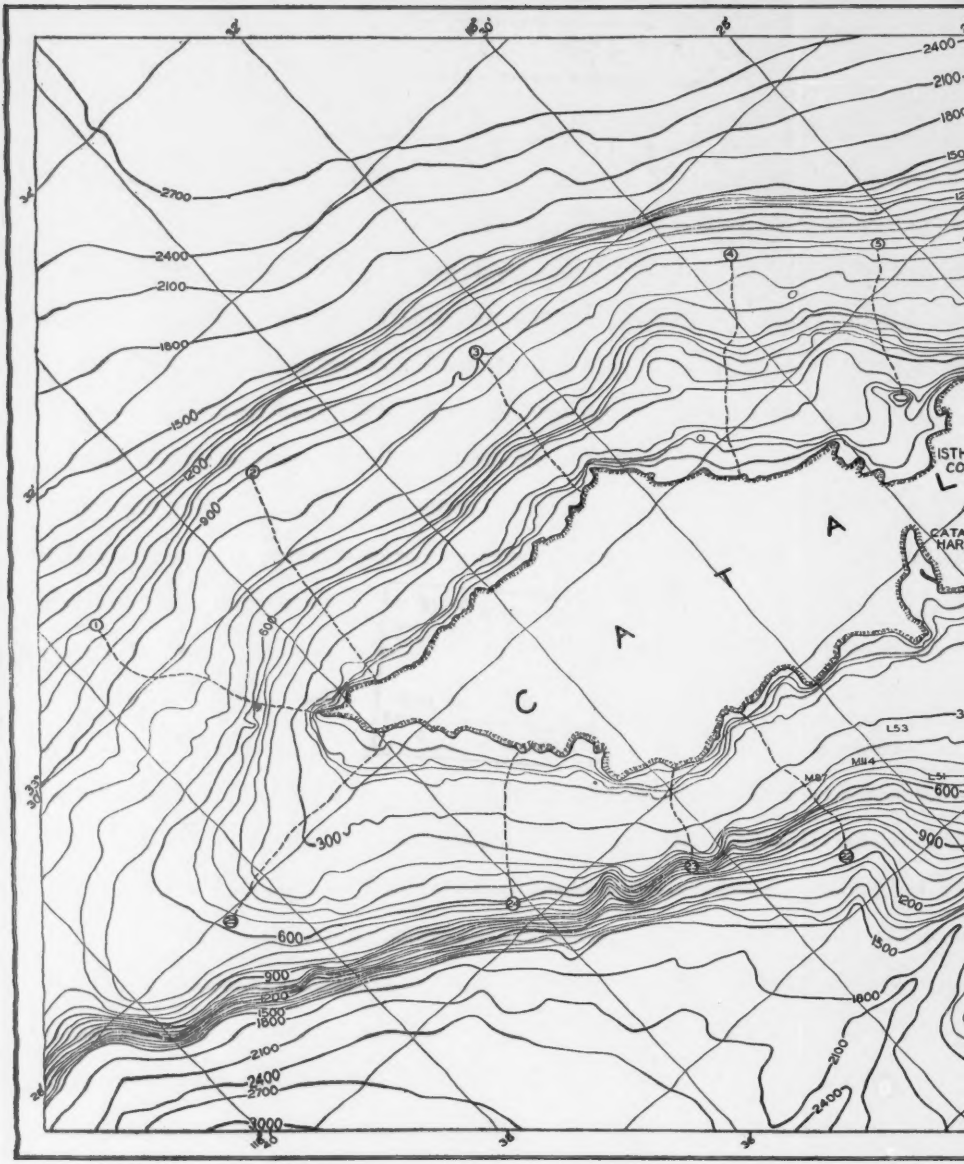
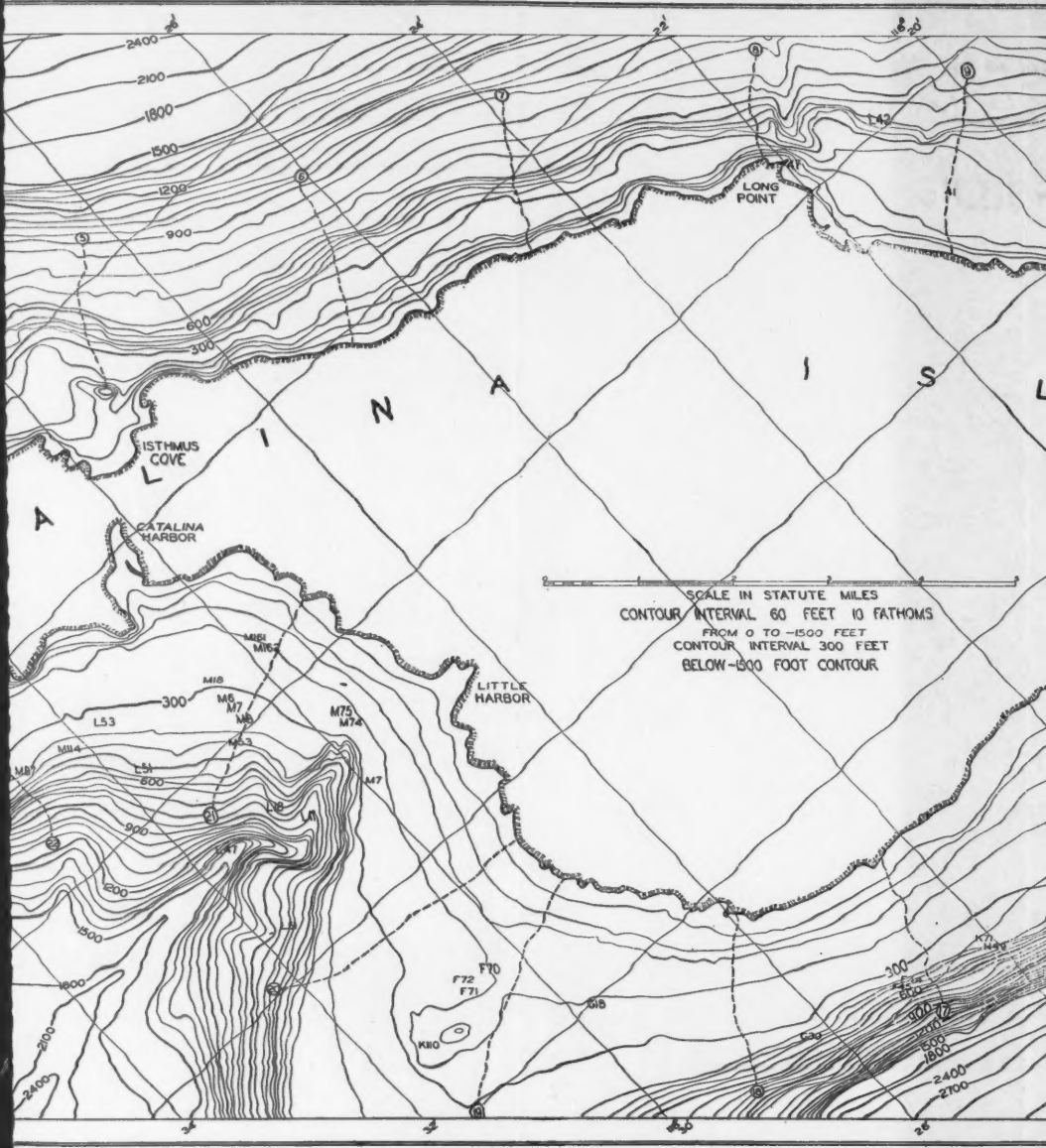
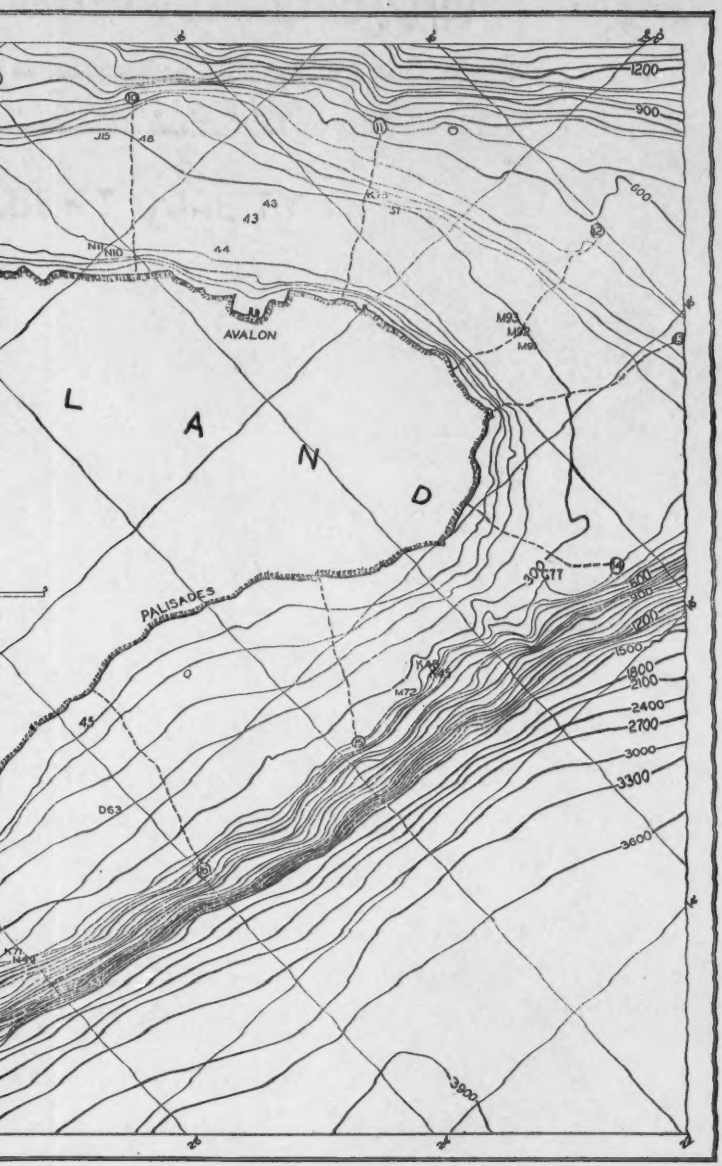


FIG. 2.—The submarine topography around Catalina Island determined from origi

rom original survey of the U. S. Coast and Geodeti



termined from original survey of the U. S. Coast and Geodetic Survey. Location of profiles in Fig. 3 shown by dashed lines a



ned lines and location of samples which were analyzed.

to show the inability of the waves to produce much transportation of the coarser grades of sediment, except in very shallow water. Off the California coast, it is a common finding that in the length of a thousand foot pier, the coarse or medium sized beach sands have graded out into very fine sands and silt.

The coarse zones at shelf margins.—Samples collected from the margins of the shelves, particularly off the south side of the island, were found to be distinctly coarser than the samples nearer shore. On the south side this meant that fine sand changed to coarse sand or even gravel, but on the northeast side where organic sediments predominate the small shells changed to large shells. No definite evidence was obtained which would afford an explanation of this change of condition, but it is not unreasonable to suppose that currents moving from the deep ocean beyond the shelf margins are concentrated at the break in slope tending to eliminate the fine material and leaving a concentrate of the coarser elements of the sediment. Probably the coarse sediment is a residue of shallow water deposition under former conditions of lower sea level. The analysis of samples from this zone has shown the presence of secondary maxima of very fine sand and silt sizes. It seems likely that these fines represent the type of sediment now being transported to the shelf margin.

We have represented here on the small Catalina shelves a condition which is found also on many of the larger continental shelves of the world.

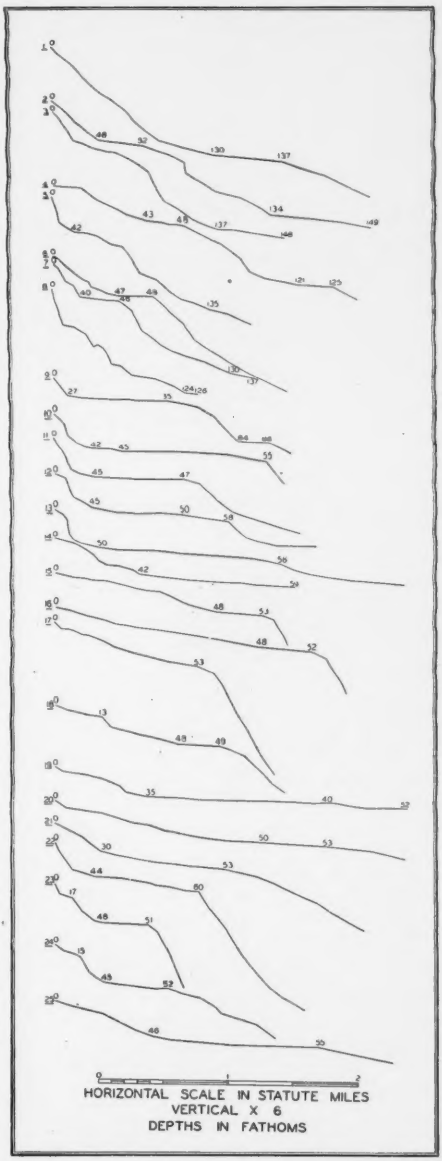


FIG. 3.—Profiles off Catalina Island showing the benches and shelves. For locations see Fig. 2.

SEDIMENT ZONES RELATED TO SHELF TOPOGRAPHY

An examination of Figures 2 and 3 will show that the bottom slopes have distinctly different character off the various portions of the island. Thus off the vicinity of Avalon there is a steep drop succeeded at 200 to 250 feet by a relatively broad flat shelf (fig. 3—profiles 9 to 12). It is on this bench that the best development of organic sediment occurs. Off the south coast the shelf slopes outward quite uniformly (profiles 14 to 20). Here fine inorganic debris forms the covering. Off the north side of the island there is scarcely any true continental shelf, but instead the slopes are almost continuous down to a deep trough (profiles 1 to 9). Along this slope some of the largest patches of rock bottom occur. Off the southwest side of the island variable slopes are found affected in part by the only sizable submarine canyon which extends out from this island (fig. 2). It is notable that silts and fine sands are the chief sediments associated with this canyon. Farther northwest along this side there is a recurrence of the same type of profile as was found off Avalon (profiles 22 to 24), although the flat portions around 250 to 300 feet are not as pronounced.

Cause of shelf off south side.—The shelf on the south and southwest side of the island is most readily explained since it is on these sides that the waves are most active. The south coast shows the most marked effects of wave erosion, particularly at the Palisades where there are sea cliffs over a thousand feet high. It is therefore interesting to note that the shelf slopes quite evenly off this area whereas in more protected areas there are steep slopes near shore and broad benches beyond.

In explaining this even sloping shelf, it should be borne in mind that the rocks of this part of Catalina are mostly hard igneous intrusives (4) which could scarcely have had shelves several miles wide cut into them since the last rise in sea level at the end of the Wisconsin glacial epoch (2). Furthermore, the depth of the outer edge, which is approximately 350 feet, is too great to be caused by the cutting action of the present day waves in a short period of time. Nor does the outer portion represent a "wave-built terrace"[3] because the steepness of the outer slope combined with the finding of rocky bottom in a number of places shows that it is essentially a rock slope and the straightness of the slope gives weight to the opinion that it is a fault scarp.

A possible explanation for the even sloping shelf is that toward the end of the last glacial epoch, when the sea probably stood 300 feet below the present level, the island was cut off by a fault along the south side. Then the waves started to cut benches at this 300 foot level and their cutting power was greatly increased by the slow rise in sea level due to glacial melting. Davis has described these conditions as being ideal for rapid benching effects. (3)

[3] The writer is unable to find any evidence that such terraces exist anywhere. (Science, vol. 78, p. 406, 1933.)

As the bench was cut back farther and the cliffs grew higher, erosion became progressively slower, so that there is no appreciable bench cut corresponding to present sea level. Perhaps the evenness of the slope is also accounted for to some extent by deposition of a thin coating of fine detritus washed out from the shore. This may have masked any minor benches which were cut during the sea level rise.

It is interesting to note that on the northeast side of nearby San Clemente Island, where another similar fault scarp is developed, there is an absence of any shelf along the coast. This may not mean so much that the faulting has been more recent off San Clemente as that the wave protected side has had no opportunity to be benched. Another analogy may be drawn from San Clemente since the south side which is subject to wave attack has the same type of even sloping shelf as the south side of Catalina.

The Avalon organic terrace.—Less easy to explain is the flat bench off Avalon. It is noteworthy that the steep slope near shore succeeded by a bench around 250 to 300 feet is found also, although less well developed, along much of the northeast coast. It appears, therefore, to have something to do with the protection from waves. The zone west of Catalina Harbor on the southwest side of the island has a smaller bench of the same general depth and an equally steep slope near shore (profile 22). Possibly some wave protection is afforded in this place, although here the explanation is not as convincing.

Several explanations for the terrace may be mentioned, although the writers do not feel that they have solved the problem. In the first place the depth which is close to 300 feet is suggestive of the Wisconsin glacial epoch sea level lowering and is a level which is well represented

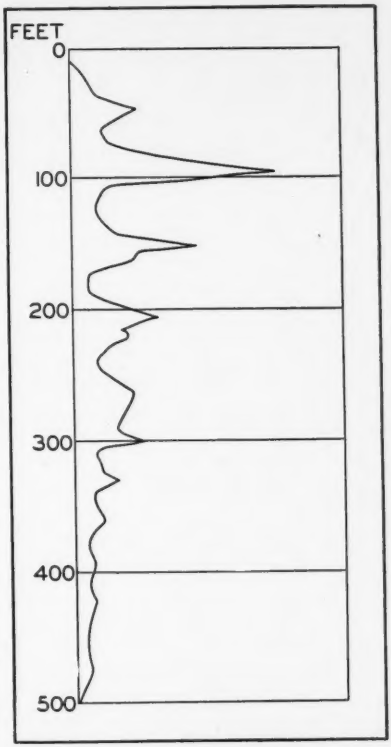


FIG. 4.—The levels at which benches are found on the continental shelves off various parts of the world, determined from studies of charts, mostly U. S. Navy Hydrographic Office and Coast and Geodetic Survey.

on various other continental shelves (fig. 4). Is it not possible that when the sea stood about 300 feet lower than now there were strong off-shore winds from the continent which allowed the cutting of benches at this level on what is now the lee side of the island? Perhaps the width of the terrace off Avalon was due to the presence of soft material at that point which is now entirely submerged. The changing climate at the end of the glacial epoch may have changed the direction of the wind and thus stopped the benching effect and as the sea level rose, the lower portion of the wave-cut cliff would have been drowned.

Another factor which may have had some bearing on the bench development is the organic sediment. It is possible that the growth of organisms with some depth control has tended to flatten an otherwise sloping surface. This, however, would have steepened the slope directly outside the bench beyond the general inclination and no such steepening is observed.

The northern and northeast sides of the island as far east as Long Point lack bordering shelves except for extremely narrow benches around 250 to 300 foot depths (profiles 1–8). The explanation for the absence of pronounced benches here may be simply that the waves are ordinarily too feeble to have produced cutting on this protected side and that the rock was too resistant to allow more than narrow benches to be cut during the episode when the Avalon bench originated.

Possible tilting of benches.—Indications of a deeper bench off the north end of the island may be seen in profiles 1 to 3. This bench occurs at approximately 800 to 900 feet below sea level. It may represent cutting at a time when this end of the island stood relatively higher. This would suggest subsequent tilting.

Similarly, the Avalon bench shows a deepening toward the southeast. This may be seen from comparison of profiles 9, 10, and 12. It will be noted that profile 11, however, does not show the same tendency. Tracing the Avalon bench to the northwest we find that it abutts against the land at Lone Point. It may be of some significance that at this point there is a small submarine valley pointing in toward the land. What this implies is not clear.

Catalina submarine canyon.—The only conspicuous submarine canyon around the island heads in toward Little Harbor. Smith has stated that this harbor is at the mouth of a structural depression between the two original main ridges of the island (4). The significance of the submarine canyon need not be discussed here since it is dealt with in a longer article (5). However, it is interesting to note that the sediment map (fig. 1) shows that the canyon walls and base are largely covered with silt and very fine sand and that the fine materials extend in nearer to the coast off this area than elsewhere. This observation adds to the other suggestions that the senior writer has found indicating that submarine

canyons are good settling basins for fine sediments.

SEDIMENT TEXTURES

Sorting of sediments.—The analyses of continental shelf sediments by various geologists has shown that sorting in this zone is notably poor, apparently less marked for example than in most ancient marine sediments and certainly less marked than in present day beach deposits. The sediments on the shelves around Catalina are no exception to this rule. Secondary maxima revealed in the plotted analyses are largely confined to the outer margins near the break in slope. On the other hand, most of the samples show a wide range in size distribution; that is, they have a high coefficient of sorting.

Shapes of grains.—The angularity of the grains is their most notable characteristic. This is particularly true of the fine sand grains. It may be of interest to note that examination of a zone near the bottom of a five foot core obtained by C. S. Piggot in 1700 fathoms off the New Jersey coast showed a sediment with marked similarity of grain shapes and general make-up to that found in 50 fathoms off the southwest side of Catalina.

PETROGRAPHY OF THE SEDIMENTS

Rock formations of Catalina.—Before discussing the petrography of the marine sediments, it would seem advisable to make a brief statement concerning the nature of rock formation from which these sediments are derived. Smith, who has studied the island more than any other geologist, so far as the authors know, gives a summary statement concerning the rock formations which should serve the present purpose, and will therefore be quoted (4–131).

> The more general geologic features of the island are simple, and, aside from the alluvium of the valley bottoms and the scant deposits associated with marine terracing, may be described briefly as follows:
>
> The northwestern two-thirds of the island is underlain by a group of metamorphic rocks which are believed to be a facies of the Franciscan series, of Jurassic (?) age. They consist chiefly of various quartz, albite and amphibole schists, tale schist, serpentine, and garnet amphibolite (hornblende eclogite), and are exposed over an area of about thirty-seven square miles, or approximately half the island. These rocks have a variable, although generally considerable, angle of dip.
>
> The southeastern third of the island consists chiefly of massive quartz hornblende diorite porphyry which has been intruded into the metamorphic rocks. This is exposed over an area of about twenty square miles.
>
> Overlying a part of both the metamorphic rocks and the porphyry is a series of volcanic flows, chiefly andesites, in part if not wholly of late-Miocene age. The principal occurrence of these rocks, having an area of about thirteen square miles, is found near the center of the island. In addition there are a number of small, scattered areas, totaling about four square miles. The largest and most northerly of these, just southeast of Isthmus Cove, contains an intercalated group of beds of tuff and diatomaceous earth, between one and two hundred feet in thickness.

According to Woodford (6), the rocks of Catalina are unusual metamorphics similar to the Franciscan series of the mainland farther north. He describes them as being of a schistose character; of variable grain;

and made up largely of various combinations of the minerals, quartz, albite, muscovite, chlorite, epidote, glaucophene, crossite, actinolite, and lawsonite. The metamorphics form the basement rocks in the western half of the island and are overlain by a volcanic series which has extensive associated intrusives. The main groups in Woodford's classification are, quartz schist, quartz-albite schist, prasinites, blue schists, and talc and serpentine rocks.

Most abundant minerals.—Quartz was found to be the most abundant mineral in the sediments collected around Catalina, averaging about 40 per cent. The albite variety of feldspar stood next with approximately 30 per cent, and muscovite third with 12 per cent.

Heavy minerals.—In the specimens analyzed for heavy minerals it was found that this group ranged from 0.01 per cent to 9 per cent of the total, with an average between 3 and 4 per cent. The greatest concentration of heavy minerals was found in the samples of coarse sand at the shelf margin off the south side of the island.

In order of decreasing abundance, the heavy minerals include epidote, actinolite, common hornblende, glaucophane, and biotite. Less plentiful are the following: lawsonite, limonite, garnet, and titanite. It was not found possible to zone the sediments on the basis of heavy-mineral content, but it is evident that the minerals present correspond with those found in the rocks on shore.

Calcium carbonate—The calcium carbonate in the sediments, as far as could be determined, is in the form of shells and shell fragments. Since no evidence of solution was noted on the surface of the organic material, it is evident that the area is now one of deposition of calcium carbonate.

Rock fragments.—Rock fragments were obtained from several places such as off Lone Point, on the east side of the submarine canyons, and on the shelf margin along the south coast. These fragments were very angular although mention should be made of one highly rounded pebble, almost one half inch in diameter, discovered in fine sediment along the north coast. The rock fragments were fine grained igneous types and schistose metamorphics. Thus they do not reveal anything different from the common types on land.

ORGANIC SEDIMENTS

Shells and shell fragments were found in most of the samples studied. In general they form only a small part of the sample, but on the shelf off Avalon Bay the shell content forms by far the greater percentage of the material. The shell content is higher in all the samples from the relatively quiet waters off the protected side of the island. The macroshells are in the main pelecypods, gastropods, and sea urchins. No identification or study was attempted of these types. The greater percentage of the micro-fossils are foraminifera. Two zones were selected for foraminifera study, one on

the southwestern platform of Santa Catalina at a depth of 50 fathoms and another in the submarine valley off Catalina Bay at a depth of 150 fathoms. As many genera of forams as could be selected were removed from the samples and sent to Mr. M. L. Natland. He identified the following genera and species:

FIFTY FATHOMS—SOUTHWESTERN PLATFORM

1. *Cassidulina* cf. *tortuosa* (Cushman and Hughes)
2. *Cassidulina californica* (Cushman and Hughes)
3. *Cassidulina limbata* (Cushman and Hughes)
4. *Cassidulina suglobosa* var. *quadrata* (Cushman and Hughes)
5. *Epistomina elegans* (d'Orbigny)
6. *Planulina depressa* (d'Orbigny)
7. *Cibicides pseudoungeriana* (Cushman)
8. *Cibicides* sp.
9. *Cibicides* sp.
10. *Globigerina conglomerata* (Schwager)
11. *Robulus cushmani* (Galloway and Wissler)
12. *Sigmomorphina frondicula riformis* (Galloway and Wissler)
13. *Angulagerina* sp.
14. *Orbulina universa* (d'Orbigny)
15. *Ostracoda*
16. *Quinqueloculina* (Young)
17. *Elphidium crispum* (Linne)
18. *Anomalina schmitti* (Cushman and Wichenden)

ONE HUNDRED AND FIFTY FATHOMS—SUBMARINE VALLEY

1. *Cancris auricula* (Fichtel and Mall)
2. *Pullenia salisburyi* (Stewart and Stewart)
3. *Bulimina ovata* (d'Orbigny)
4. *Martinotiella communis* var. *pallida* (Cushman)
5. *Cassidulina limbata* (Cushman and Hughes)
6. *Bolivina argentea* (Cushman) microspheric and megalospheric
7. *Bolivina* sp.
8. *Globigerina conglomerata* (Schwager)
9. *Cassidulina subglobosa* var. *quadrata* (Cushman and Hughes)

Also *Unigerina* cf. *tenuistriata* (Reuss)

Natland called attention to the comparison between the species found in this second sample from the seaward side of Catalina with those which he had described from the protected northeast side (7). He found that the group contains a transitional fauna between his Zone III, which extends from 125 to 900 feet, and his Zone IV, which extends from 900 to 6,500 feet. This suggests that the same depth limitations apply to the foraminifera on the muddy slopes off the exposed side as on the organic slopes off the protected side.

ACKNOWLEDGMENTS

The senior writer is indebted to the Coast and Geodetic Survey for permission to accompany one of their vessels on the trips when the samples were collected. The help of Lieutenant R. W. Knox who was in command was particularly appreciated. Grants from the graduate school of the University of Illinois have helped in preparation of the illustrations. The writers are also appreciative of the kindness of Mr. Manley Natland in identifying the species of foraminifera sent to him.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 7, NO. 2, PP. 51–54, AUGUST, 1937

A METHOD FOR THE MINERALOGICAL FRACTIONATION OF SEDIMENTS BY MEANS OF HEAVY LIQUIDS AND THE CENTRIFUGE

ERNEST BERG
University of Minnesota

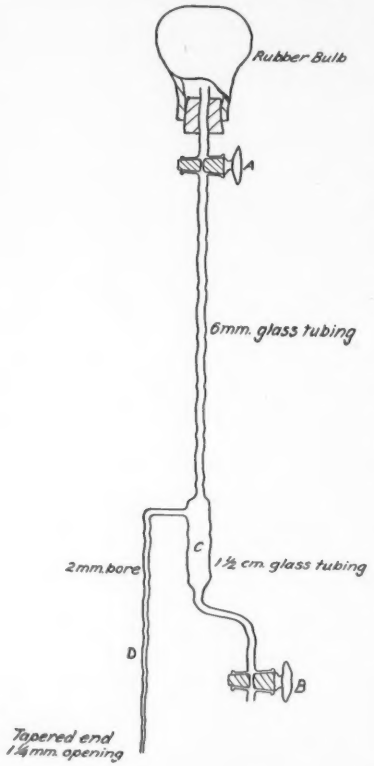
The most common fractionation of sediments is the separation of the heavy minerals from quartz and other minerals with a specific gravity less than bromoform (2.88). In the sand sizes this separation can be done efficiently under the acceleration of gravity. In silts the separation under gravity is slow and incomplete. It is common practise, therefore, to allow the heavy minerals of the silt to separate under centrifugal force.

While a gravity separation of the heavy minerals of a sand can be made readily because of the great difference in the specific gravity of quartz (usually the bulk of the sample) and the specific gravity of the heavy minerals, it is not so easy to separate minerals which are close to each other in density. The gravity separation of potash feldspar and albite from quartz, for example, is a difficult task and usually requires repeated separations. By using a heavy liquid in centrifuge tubes the separation is much quicker and produces cleaner separates. With full strength or diluted Thoulet's solution or bromoform it is also possible to isolate or concentrate carbonates, glauconite, the micas, diatoms and other materials. Minerals may also be separated from crushed rocks for X-ray or chemical analysis.

Separatory funnels of the type commonly used for gravity separations cannot be used satisfactorily in the centrifuge. Although these funnels, with the proper trunnions, are on the market, the funnel stopcocks will not hold heavy liquids when subjected to centrifugal force. It is necessary, therefore, to use tubes which are sealed at one end. Sealed tubes, however, have one disadvantage. After the separation of the heavy and the light or floating fractions by centrifuging, it is difficult to remove the floating fraction from the heavier material which has settled in the bottom of the centrifuge tube. A qualitative sample of the lights may be obtained by decantation while most of the heavy minerals may be removed by an ordinary pipette.

More accurate methods permitting quantitative separations have been reported. Wolff (1) secured quantitative results by placing a pipette-like tube inside of an ordinary centrifuge tube. The heavy liquid was placed inside of and around the pipette tube but the sediment was placed only on the inside of the pipette tube. After centri-

fuging, the top of the pipette was closed and the pipette withdrawn, leaving the heavier fraction on the bottom of the centrifuge tube. Brown (2) found that quantitative separations could be made by sealing a



glass tube 2 cm. long, with a bore of 4 mm., to the bottom of an ordinary centrifuge tube. After separation, the heavies were recovered by filing and breaking off the small glass tube. Taylor (3) reported good results from the use of a centrifuge tube of the Penfield type.

The writer has designed and used with consistent results, a pipette such as is illustrated in the accompanying figure. The essential features are (1) a small glass tube (D) 16 cm. long with a 2 mm. bore but tapered to a $1\frac{1}{4}$ mm. opening at the lower end, (2) a trap (C) which collects the sediment carried through the small tube by the rising heavy liquid, (3) a stop-cock (B) which permits drainage of the trapped sediment into a filter paper, and (4) a rubber bulb which can be closed off from the rest of the pipette by a stop-cock. The pipette is mounted on a ringstand.

In making separations, about one gram of sediment is placed in a 15 ml. centrifuge tube and 15 ml. of the proper heavy liquid added. Most complete separations are obtained if the amount of sediment in a tube is not too great. If it is desired to use several grams of sediment it is better to run duplicate sets by using two or four tubes. After the sediment and heavy liquid have been placed in the tube it is closed with a cork stopper and thoroughly shaken to disperse all of the sediment. To prevent lodgement of silts between the stopper and the tube, the sediment may first be dispersed by shaking it in a glass-stoppered bottle, and the resulting suspension may then be washed into the centrifuge tube.

The tube is then placed in the centrifuge and run until the liquid is clear. When using commercial pyrex centrifuge tubes with heavy liquids it is not safe to develop a

centrifugal force of over 1,000 times gravity. The pressure of the heavy liquid is apt to break the tube. During the run in the centrifuge, the heavy liquid tubes should be stoppered to prevent wastage of the full strength liquids as well as to prevent change of density in the diluted liquids.

The pipette described above is used to remove the heavier fraction which has separated during centrifuging. The rubber bulb is pressed and the bulb stop-cock (A) closed. The lower stop-cock (B) is closed also. The centrifuge tube is then raised under the small glass tube (D) until the end of the tube rests on the bottom of the centrifuge tube. Then the bulb stop-cock is opened allowing the heavy liquid to rise slowly in the pipette and to flow into the trap. The heavy minerals are carried along with the liquid.

When the heavy minerals have been removed from the bottom of the centrifuge tube the stop-cock is closed. The centrifuge tube is lowered until the opening of the pipette is above the liquid in the tube. The bulb stop-cock is then opened slightly, clearing the small pipette tube of the liquid remaining in it. The stop-cock is then closed. The lights remaining on the outside of the pipette are washed down into the centrifuge tube with a heavy liquid identical with that in the tube.

The material in the pipette trap may then be released into a filter paper by opening the lower stop-cock. Ordinarily, however, the writer empties the trap into a second centrifuge tube. In the meantime the first tube is refilled with the heavy liquid, thoroughly shaken and again centrifuged. The heavy grains are removed a second time from this tube and added to those already in the second centrifuge tube. If too much sediment was not used, the material in the first tube will be practically free of the heavier mineral grains. The second tube contains the heavies and whatever lights may have been picked up by the pipette in going through the floating mass. In coarser material the pipette does not pick up much contamination. In the finer sediments, however, there may be some contaminating grains. The second tube is then filled and centrifuged. The lights will form only a thin coating on the surface of the liquid in this tube so that the pipette can pass through without contamination. The heavy minerals are again withdrawn and the lights added to those in the first tube.

Repeated experiments have shown that the pipette described above can be relied upon to remove heavy grains varying from $\frac{1}{2}$ mm. to 1/128 mm. in diameter. Grains smaller than 1/128 mm. cannot be identified under the microscope. The pipette is not designed for work with fine powders or clayey material. Its efficiency is greater for sand than for silt. Five mililiters of the heavy liquid will remove about $\frac{3}{4}$ of a gram of silt while the same amount of liquid will carry more than 1 gram of sand. The efficiency is nearly independent of the specific gravity of

the separated grains, since equal amounts of liquid will lift approximately equal volumes of quartz sand and magnetite sand. The capacity of the trap is 8 ml.

This pipette has several advantages over other methods of separation. First, ordinary centrifuge tubes can be used. Second, it permits a better separation since the first separates are thoroughly shaken and again reseparated. Third, the trap permits no loss of the heavy grains. With an ordinary pipette many grains settle back into the centrifuge tube before the pipette can be removed from the heavy liquid.

Progressive separations of one sediment can be made. The lights may be dried and placed in a heavy liquid of lower specific gravity than the first liquid. The same technique is then followed. By using this method the writer separated the material from the summer layers of varved glacial silt into several of its components, including the ordinary heavy accessory minerals, the carbonates, quartz and acid feldspar. Slides of these separates show very little contamination by minerals of different specific gravities.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 7, NO. 2, PP. 55–66, FIG. 1, TABLES 1–4.
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BOTTOM DEPOSITS OF THE ROSS SEA

H. C. STETSON AND J. E. UPSON
Harvard University

Contribution No. 130 of the Woods Hole Oceanographic Institution

ABSTRACT

The Ross Sea is floored with glacial debris upon which the sea has exercised no selective action whatsoever. The sediment is apparently being laid down in the same condition in which it is being released by the melting ice. Distance from the ice barrier and depth of water have no effect on texture. The Antarctic continent is surrounded by a zone of this material 200 to 500 miles wide, which mantles the continental shelf and slopes. It might be termed a marine till. The percentages of clay and colloid run unusually high. Such complete lack of sorting is unusual in either a deep or shallow water marine sediment, even in the Arctic where the deposits are also largely laid down by floating ice.

Among the heavy minerals, those of the ferro-magnesian group are unusually abundant. All the heavies are comparatively unaltered, which is undoubtedly due to glacial conditions. Higher grade metamorphic minerals are notably absent. In the finer grades chemically decomposed material is found which is probably due to the glacial grinding of shales rather than to present conditions either on land or in the sea.

This paper presents the data of the mechanical and mineralogical composition of twelve cores obtained on the "Bear" by Edward Roos during the course of the second Byrd Antarctic Expedition. They are all located within the Ross Sea and the great majority along the front of the ice barrier (fig. 1). Although the cores are widely separated, the study seemed worth while because of the small number of bottom samples which have been obtained from this area, and because in its deposits we are dealing with a rather unusual type of marine sediment; one which has been laid down directly from a continental ice sheet with little or no modification. In the section dealing with the mineralogy, the data is insufficient to warrant more than a purely descriptive and qualitative report.

Our thanks are due to Professor Esper S. Larsen for much valuable criticism concerning the mineralogical examination.

MECHANICAL ANALYSIS

The method used for mechanical analysis was the combined sieve and hydrometer technique devised by Professor Arthur Casagrande. Before analysis the salt content of the sediment was removed by repeated washings, the water being drawn off through Pasteur-Chamberland filters by means of a vacuum pump. An account of this procedure is given elsewhere and further description is unnecessary here (1).

An attempt was made to use the statistical constants devised by Trask (2) for sorting and skewness, which are based on the relationships of the first and third quartile diam-

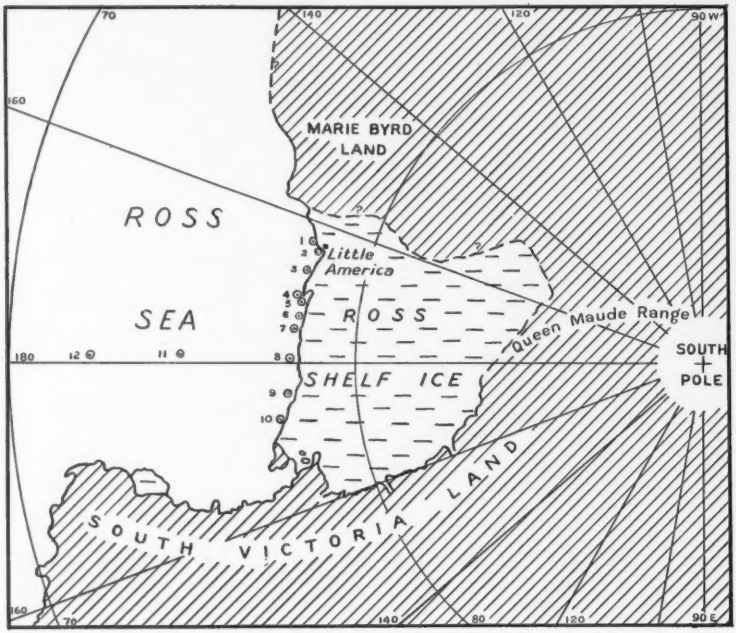

FIG. 1.—Positions of bottom coves.

TABLE I

Stations	Lat.	Long.	Depth, M.
1	78°–30′	S. 163°–40′ W.	642
2	78°–32′	164°–06′ W.	644
3	78°–20′	167°–17′ W.	530
4	78°–17′	170°–44′ W.	558
5	78°–20′	171°–37′ W.	539
6	78°–19′	173°–09′ W.	446
7	78°–16′	175°–37′ W.	545
8	78°–11′	179°–42′ W.	807
9	78°–00′	176°–35′ E.	803
10	77°–37′	172°–45′ E.	794
11	74°–57′	178°–45′ W.	520
12	72°–27′	178°–37′ W.	2571

eters to each other and to the median diameter. These quartiles are derived from a cumulative curve—75 per cent of the sample is finer than the diameter of the first quartile and 25 per cent finer than the third. It is generally agreed that it is not practicable to carry the mechanical analysis of a sediment further than one micron. Beyond this point the particles in suspension are so small that Brownian movement begins seriously to interfere with settling velocities. Consequently all calculations for grade sizes, based on Stokes Law, are subject to considerable error. In 16 out of the 24 samples analyzed, the portion of the sample smaller than one micron is more than 25 per cent of the entire sample; 40 per cent and more is common, and in one case it runs as high as 51 per cent. In many cases, therefore, it is impossible

to derive the third quartile diameter without extending the curves beyond the limits of accuracy.

The coefficient of sorting is obtained by substitution in the formula $So = \sqrt{\frac{Q1}{Q3}}$. Thus perfect sorting equals unity. The experience of the present authors with many samples has given an average value of 1.25 for beach sands, and of 1.45 for well-sorted, near-shore, sediments.

The coefficient of skewness is derived from the formula $Sk = \frac{Q1 \times Q3}{M^2}$. It indicates on which side of the median diameter, and how far from it, the mode, or peak of size distribution lies. For ease of interpretation, i.e., to show readily on which side of the median the mode lies and its relative divergence, the logarithm of the skewness is given. Thus a log of 0.0 ($Sk = 1$) indicates a symmetrical size distribution curve, the mode coinciding with the median; a plus log (Sk greater than 1) that the mode is on the fine side of the median; a minus the opposite. For full details Trask's papers should be consulted.

PREVIOUS INVESTIGATIONS

Our knowledge of the bottom deposits surrounding the Antarctic continent is mainly derived from the voyages of seven vessels—"Challenger" (3), "Valdivia" (4), "Gauss" (5), "Scotia" (6), "Aurora" (7), and of recent years "Discovery" and "William Scoresby" (8). Most of them ran lines of soundings across the southern oceans to Antarctica. "Challenger" approached what is now Kaiser William II Land and Termination Ice Tongue and thence proceeded to Melbourne. "Gauss" followed nearly the same route as "Challenger's" south bound track, going south and returning via Kerguelen. "Valdivia's" track lay somewhat to the west, from Bouvet Island to Enderby Land thence north to Kerguelen. "Scotia" crossed from the Falkland Islands to the Weddell Sea and thence northwards approximately along 10 W. Long. "Aurora" made several trips back and forth between Hobart and Adelie Land usually via Macquarie Island. "Discovery" and "William Scoresby" have sampled mostly in and around the Antarctic Archipelago, between these islands and Cape Horn, around south Georgia and in the Bellingshausen Sea.

It is evident from the above resume that the bottom deposits of the southern oceans are known, at least in a general way, from 160 W. Long. westward to about 90 E. Long. The remaining gap has been partly filled by the Ross Sea samples obtained by the "Bear."

DISTRIBUTION OF SEDIMENTS

Our knowledge can by no means be considered detailed, and it is of course impossible to delimit accurately the boundaries between the various types of deposits. Enough data, however, have been assembled to give an idea of their general distribution.

Antarctica is surrounded concentrically by three types of sediments.

Immediately encircling the continental margin is a zone of terrigenous material. This was originally put in the "blue mud" group according to Challenger Reports, but subsequent work has shown that it possesses very different characteristics from the terrigenous sediment commonly found in deep ocean basins. Philippi (5) and Pirie (6) have termed it a glacial marine deposit.

According to them it differs from "blue mud" in its very poor sorting, having a wide range in the size of its constituent particles, in its almost complete lack of $CaCO_3$, and low organic content. The "fine washings" consist largely of "rock flour" and the remainder of clay minerals. The samples consisted "essentially of a mixture of the finest ooze with sandy and gravelly constituents and here and there large fragments and stones." Chapman (7) is obviously dealing with the same type of material in his near-shore samples, though his descriptions are not so full.

Lying to the north of the glacial marine deposits is the zone of diatom ooze. Neaverson (8) has called attention to the intergradation of the deep sea deposits with one another, and the consequent difficulties of classification. Here the contact between the two zones was sampled in greater detail than was done by the other ships in their areas, and the terrigenous material was found to grade gradually into the organic ooze, with no sharp contact. Were comparable data available, it is probable that this condition would be found to exist all around the continent, and we would not find the clear cut boundaries that Philippi and Pirie imply. The width of the terrigenous zone is likewise variable, but in general it appears to extend 200 to 500 miles from the continental margins. Beyond the diatomaceous ooze lies the globigerina ooze characteristic of the deeper parts of all the southern oceans.

DESCRIPTIVE DATA

The Ross Sea lies entirely within the inner zone of glacial marine deposits, as the samples under consideration indicate. Table II lists the median diameters of the size distribution of each sample. Table III gives the percentage composition of each sample split up into arbitrary grade sizes, which are also taken from the cumulative curves. A table of this sort has all the disadvantages of a histogram, but if the faults are borne in mind, it is useful for a general survey. A section 5 to 7 cm. in length was taken from the top and bottom of each core, and in the case of core 12 one from the middle as well. The coring tube used had an inside diameter of about 1 inch, which necessarily limits the maximum size of the particles. Much larger rock fragments were obtained with another type of dredge. As most of the fine fractions were washed out when using this instrument, the samples were not analyzed.

Samples 1 to 10 were taken directly along the front of the ice barrier for a distance of nearly 300 miles. Their depths range from 446 to 807 meters.

TABLE II. *Statistical Constants*

Core	Length in cms.	Q1	Millimeters Median	Q3	So	Log Sk
1	32					
Sec. 1			0.0009			
Sec. 2			0.0012			
2	37.5					
Sec. 1			Flocculated			
Sec. 2			0.0029			
3	32					
Sec. 1			0.0032			
Sec. 2			0.0013			
4	35					
Sec. 1			0.0014			
Sec. 2			0.0017			
5	38					
Sec. 1			0.0017			
Sec. 2			0.0012			
6	30					
Sec. 1			0.0050			
Sec. 2		0.2250	0.0290	0.0010	15.0	−0.55
7	33					
Sec. 1		0.4900	0.0250	0.0009	23.2	−0.15
Sec. 2		0.4150	0.0820	0.0019	14.8	−0.93
8	30					
Sec. 1			0.0015			
Sec. 2		0.1620	0.0190	0.0019	9.2	−0.07
9	34					
Sec. 1			0.0031			
Sec. 2		0.2200	0.0210	0.0016	11.7	−0.10
10	36					
Sec. 1			0.0014			
Sec. 2			0.0016			
11	28.5					
Sec. 1		0.8100	0.1600	0.0260	5.5	−0.08
Sec. 2		0.1700	0.0140	0.0010	13.1	−0.06
12	53					
Sec. 1			0.0039			
Sec. 2		0.1020	0.0360	0.0021	6.9	−0.78
Sec. 3			0.0051			

The median diameters are all small, never exceeding 0.08 mm., and with the majority in the neighborhood of 0.001 mm. A marine sediment with a value for So. of 1.45 is considered well sorted, and values of 3 or 4 are not often exceeded. Consequently values ranging from 6.9 to 23.2 indicate that the sorting is very poor. In fact, some of the samples can scarcely be said to be sorted at all, so nearly equal is the proportion of material

TABLE III. *Percentage Composition*

Sample		Gravel 1–30 mm.	Sand 0.05–1 mm.	Silt 0.005–0.05 mm.	Clay 0.001–0.005 mm.	Colloid 0–0.001 mm.
Core 1	Sec. 1	4	6	14	25	51
	Sec. 2	9	7	13	24	47
Core 2	Sec. 2	1	28	14	13	44
Core 3	Sec. 1	16	9	19	21	35
	Sec. 2	0	8	23	21	48
Core 4	Sec. 1	0	6	24	25	45
	Sec. 2	2	8	25	22	43
Core 5	Sec. 1	1	9	24	24	42
	Sec. 2	1	11	17	24	47
Core 6	Sec. 1	4	23	23	18	32
	Sec. 2	11	34	18	12	25
Core 7	Sec. 1	20	27	16	11	26
	Sec. 2	14	40	15	11	20
Core 8	Sec. 1	2	13	18	23	44
	Sec. 2	13	26	26	15	20
Core 9	Sec. 1	5	18	20	21	36
	Sec. 2	9	34	22	15	20
Core 10	Sec. 1	0	8	23	26	43
	Sec. 2	0	7	21	31	41
Core 11	Sec. 1	23	49	13	10	5
	Sec. 2	10	30	18	17	25
Core 12	Sec. 1	0	20	26	19	35
	Sec. 2	4	41	35	6	21
	Sec. 3	0	21	30	16	33

in the different grades. The percentage of colloid runs unusually high, as does that of gravel. The combination of the two is responsible for the poor sorting. Core 11 is situated on the shelf about 210 miles seaward from the barrier. It displays the same characteristics as those just beyond the ice front. Core 12 was taken beyond the continental margin in 2571 meters of water. In spite of the depth of water, the material is very similar to that covering the shallower bottoms. The median diameters are no smaller, and the same lack of sorting due to the same causes, is present. Distance from the present ice front, and the depth of the water have no effect, per se, on texture.

The textural difference between the tops and the bottoms of the cores have no apparent significance. The same small median diameters and the same lack of sorting hold throughout. There is no tendency for any particular grade size to be dominant in either the top or the bottom. Environmental conditions under which

the lower parts of these short cores were deposited were, therefore, similar to those controlling deposition at present.

Pirie (6, pp. 683–684) states that the percentage of grade sizes larger than 0.02 to 0.05 mm. in diameter averages 16.7 per cent of the whole sample; and that the "fine washings," including everything below these limits, averages 82 per cent. He also emphasizes the fact that "rock flour" constitutes the bulk of these grade sizes by comparing them to clay from the Portobello brick field near Edinburgh, from which he says they are microscopically indistinguishable.

A precise definition of rock flour is needed. Pirie apparently uses this term to signify material which is composed almost entirely of fresh, sharply-angular mineral or rock fragments. It should be pointed out here that glacial gouge, or rock flour, of the above description can only be obtained by the scouring of crystalline rock surfaces. Rock flour derived from a shale would probably contain a large proportion of kaolin or other clay-like constituents. Pirie's methods of determination could not have been so critical as those of today.

In order to determine the relative amounts of "clay" and "rock flour" in the sediments from the Ross Sea, samples of cores 2, 5, 8, 10, and 12 were studied with a high-power oil immersion lense. No mineral separations were conducted, and the finest sizes of material could be studied, whereas in examining the heavy minerals, only the sand sizes were considered. The cores chosen are well-distributed over the area of the Ross Sea floor, and are taken to be representative of the whole. The relative amounts of the different constituents were estimated.

The proportion of fragments of diatoms and other organisms is high, amounting to as much as 50 per cent in some samples. There is a fairly high percentage of coarse mineral fragments, most of which are angular or subangular, although some are definitely rounded. There is an appreciable number of tiny grains so small as to be barely determinable as mineral particles. Many of these are muscovite or sericite, minerals which are often the result of alteration. Some of the feldspar grains are partly sericitized.

In addition there are many masses of tiny mineral fragments held together apparently by a matrix of clay-like material. The proportion of these rounded masses is in some samples as high as 25 per cent. This figure should not be taken as giving the actual percentage of "clay," since "clay" constitutes only part of these masses. The total proportion of angular mineral fragments is in every sample somewhat less than 50 per cent. If the organic material be ignored, however, this figure would be considerably higher. It is indicated, then, that at least 50 per cent of the rock debris studied might be considered "rock flour." However, the presence of some rounded grains, sericite, and the amorphous masses of tiny grains indicates that an appreciable, though not a major, part

of the Ross Sea material is the product of weathering. This may be explained by the glacial erosion of sedimentary and metamorphic rocks which may contain decomposition and alteration products. Glacial debris need not consist entirely of fresh angular particles.

HEAVY MINERAL CONTENT

Only the material of sand grade and larger was examined. The sands were subdivided by screening into four sizes: (1) greater than 1 mm. in diameter, (2) less than 1 mm. and retained by a 64 mesh screen, (3) passed by the 64 mesh screen and retained by a 130 mesh screen, and (4) that passing a 130 mesh screen. The heavy minerals were isolated by the use of bromoform, specific gravity 2.89. The material of the first two screen sizes contained many unbroken and undecomposed rock fragments, though the mineral content was qualitatively the same as that of the finer sizes. Consequently only the finer fractions were separated into heavy and light components; and the percentage of heavy minerals by weight was measured only for those sizes. The minerals were identified by optical methods.

The relative abundance of the different heavy minerals was estimated and the minerals classed as indicated in the accompanying table. No differences were observed between the top and bottom of any one core. Each is consequently treated as a unit in the table. Core 2, Section 1, had so little material in the sand grade that it was not analyzed.

The material of gravity less than 2.89 contains almost entirely quartz and feldspar (orthoclase and some plagioclase), with a little muscovite (partly sericite), and numerous rock fragments. The fragments consist of granite (both pink and gray), lava (probably basalt or andesite), felsite, biotite schist, some quartzite, pebbles of gray sandstone, arkosic sandstone or fine-grained conglomerate, slate, and some fragments of serpentine. The igneous rocks are by far the most abundant.

In addition to this material which was in the cores, some pebbles and boulders brought up by dredge from the Bay of Whales were examined megascopically. These were similar to the fragments in the cores. Curiously enough, undoubted glacial striations were visible on only one fragment, a slate.

As indicated in Table IV the percentage of heavy minerals varies from 2 to 8. In nearly every core, the finer size contained a higher percentage than the next coarser grade. In general, all the material is fresh. However, the pyroxene and hornblende were slightly weathered in some of the cores. In the light fraction a few of the feldspars show some alteration. Nearly all the grains are angular, though some of the zircon and quartz grains, probably derived from the sediments, are rounded. No difference was observed, either in mineral content or in degree of alteration, between the top and bottom of any one core. This suggests the absence of weathering on the sea floor, though the cores are only about

TABLE IV

Core	1	2	3	4	5	6	7	8	9	11	12
Heavies in grade 3:	6%		3%	5%	2%	4%	4%	3%	5%	6%	5%
grade 4:	6%		6%	4%	4%	6%	7%	3%	8%	7%	6%
Minerals											
Pyroxene	C	D	R	C	A	A	A	C	A	D	A
Hornblende	A	C	A	A	—	C	C	C	C	C	C
Biotite	A	R	C	A	C	—	C	A	C	C	C
Epidote	C	C	C	R	R	R	A	C	C	C	R
Opaques	C	C	C	C	C	C	C	R	C	R	C
Garnet	R	R	R	R	R	R	R	R	R	R	R
Kyanite	R	R	R	R	R	R	R	R	R	R	R
Sphene	—	R	R	R	R	R	R	R	R	R	R
Zircon	R	R	R	R	R	R	R	R	R	R	R
Calcite	T	R	T	T	—	—	—	T	T	—	R
Tourmaline	—	T	T	T	T	T	T	T	—	—	T
Chlorite	R	T	R	—	T	R	T	—	—	—	—
Olivine	R	T	—	—	—	—	T	T	T	T	—
Clinozoisite	R	—	C	—	—	—	T	T	T	R	R
Rutile	—	—	T	T	T	T	—	—	—	T	—
Zoisite	—	R	R	C	R	—	—	—	—	R	R
Apatite	—	T	T	T	T	—	T	—	—	—	—
Chloritoid	—	T	T	—	—	—	—	—	T	—	—

NOTE: In addition to the above, a few grains of vesuvianite, topaz, and chiastolite were identified. Most of the pyroxene is augite, though some hypersthene is present in most of the cores. The letters indicate the following percentages: "D": more than 50 per cent of total, "A": 50 per cent to 20 cent, "C": 20 per cent to 5 per cent, "R": 5 per cent to 1 per cent, "T": 1 per cent or less.

1½ feet long. The only difference between cores is a rather pronounced decrease in the relative abundance of pyroxene in cores 1, 3, 4, as indicated in the table; and a less noticeable decrease in cores 5 and 6. The difference was apparent to the observer, but too small to be expressed by the percentage subdivisions used. Epidote is conspicuously rare in cores 4, 5, 6 and 12. In general, there is an accompanying increase in the amount of hornblende and biotite. All these cores were taken (with the exception of 11 and 12) off the edge of the Ross Sea Ice barrier. This may indicate a different source terrain for the sediments of that area.

CONCLUSIONS

The type of sediment which surrounds Antarctica is, as far as is known at present, unique among marine deposits. It mantles the continental shelf and slope, in general, down to about 2,000 fathoms. Pirie reports it as deep as 2,764 fathoms in one instance. The older techniques of mechanical analysis were inadequate for separating a sample into its constituent parts. Hence the data from these samples are not as complete as those which can be obtained by present day methods. Nevertheless, from the descriptions in the older reports, it is obvious that the zone of terrigenous material which the various vessels crossed in approaching the continent is the same type of deposit which floors the Ross Sea.

The continental ice sheet is responsible for this deposit, which has has all the characteristics of a till

laid down on land. The remarkable fact is how little influence the sea appears to have had upon it. Such a complete lack of sorting is unusual for marine deposits. Furthermore, the material deposited directly in front of the ice barrier is the same as that laid down 300 miles seaward. This uniform distribution is apparently characteristic of the whole width of this belt of sediment which surrounds the continent, as nearly as can be ascertained from the older analyses of samples taken in other parts of the area. The heterogeneous mixture of coarse and fine particles would indicate that deposition from melting icebergs is constantly taking place throughout the whole region. Marine currents have had little or no sorting effect upon the sediment, either while it was settling out or after its deposition. Nor do distance from shore or depth of water have any appreciable influence on texture, although were more samples available it would probably be found that there was some diminution in the median diameter towards the outer margins of this belt. In fact, Pirie states that his samples from the northerly parts of the Weddell Sea contain more amorphous clay than any of the others. The depth of water places these sediments well beyond the reach of wave action, so that once on the bottom the deposit apparently remains unaltered.

The major characteristics of the minerals are the freshness and angularity of the grains, the relative abundance of the heavy minerals as a whole, and the ferro-magnesian group in particular. The marked absence of higher-grade metamorphic minerals such as staurolite and sillimanite is worthy of record. This suite of minerals is the product of the two factors: constituents of the eroded rocks, and the manner of weathering and transportation. No minerals were identified which could not have been derived from the observed types of rocks. They are the same as those reported by Gould (9) from the Queen Maude Mountains. The mineral suite agrees well with Stewart's (10) petrographic description of specimens of the biotite schist collected by Gould. Exposure of considerable areas of basaltic rocks is suggested by the large proportion of pyroxene and other dark minerals. Gould observed diabase intrusives in some areas. The freshness and angularity of the material, and the great quantity of the more easily decomposed ferro-magnesian minerals, is explained by the presence of ice as the agent of transportation, and the presumed dominance of mechanical weathering.

The percentage of clay and especially colloid in these deposits runs unusually high, due to the failure of marine currents to elutriate the finer particles. By way of comparison, Thorp (11) gives the figures for the mechanical analyses of several samples in deeper parts of the Atlantic, as does Trask (2) for various localities all over the world. Rarely do the percentages for these two grade sizes reach the figures that are generally found here. These grades are by no means entirely

composed of fresh angular fragments, but considerable quantities of chemically altered material are present. As pointed out above, the altered material is probably derived from pre-existing sedimentary rocks.

For the sake of comparison let us examine some sediments from two areas in the Arctic which in large measure likewise owe their origin to floating ice, namely Davis Strait and the Polar Basin itself.

Trask (12) has analyzed the sediments brought back by the "Marion" Expedition from the Davis Strait region. In addition to the usual methods for transporting and distributing marine sediments, bergs of glacial ice and floes of sea ice, which pick up material from the shore line, also play an important part.

This material is much sandier than the Antarctic sediments which we have been considering, which is, of course, reflected in correspondingly larger values for the median diameter. The sorting, however, except for an occasional sample, is much better. It is evident that here marine currents are exerting some selective action on the heterogeneous mass of glacial debris which is being constantly delivered to them. This sorting may take place while the material is settling from the surface, or the bottom itself may be swept by currents of sufficient velocity to remove the finer grades.

In the Arctic Basin proper (1) we have yet another type of deposit, resulting from floating ice. Like the Antarctic deposits, it contains unusually large amounts of clay and colloid for a marine sediment, with equally small median diameters, but the sorting is good. It does not possess the usual characteristics of a deep-water marine clay, but more nearly resembles a fluviatile one. Its mode of origin is utterly different from the material being deposited in the oceans at the other pole. The ice of the Arctic Basin is all salt-water ice. There are no bergs present which originated in glaciers. During the winter an ice platform forms over the broad Siberian continental shelf, with its inner margin frozen solidly to the land. The spring freshets of the Siberian rivers start in the south while this ice is still fast to the shore. In the consequent flooding of the surface of the ice-floes much river sediment is carried out upon them. Eventually, as the spring advances, these floes break loose and drift away with their load of sediment to join the main polar ice-pack. There is ample opportunity for this material to be dropped during the extensive melting of the summer. It is probable that the ordinary marine agencies supply some of the material for this deep water clay, but the direct deposition of river sediment by the ice plays a larger part.

The marine sediments at the two poles exhibit great diversity. The fact that neither region has emerged from the Ice Age does not make for uniformity of conditions of sedimentation, which at first glance one might be led to expect. Were these

sediments ever to be consolidated and form part of the geologic column, from the Davis Strait region, and in all probability off the whole west coast of Greenland, we should have a poorly-sorted marine sandstone, still retaining traces of its glacial origin; in the Arctic Basin would be very fine-grained shales giving no textural indication that they had ever been associated with ice or an Arctic climate; while on the continental shelf and slopes of Antarctica one should find a vast deposit of tillite. Sedimentary environments, under an Arctic climate, it appears, may be just as varied as under more temperate conditions.

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THE BOTTOM SEDIMENTS OF LAKE MONONA, A FRESH-WATER LAKE OF SOUTHERN WISCONSIN

W. H. TWENHOFEL
University of Wisconsin

ABSTRACT

The bottom sediments of Lake Monona consist at the top of a black sludge dominantly composed of insoluble matter, of which most is silica, calcium carbonate, and organic matter. Beneath the sludge are light-colored, firm sediments which are composed of 60 to 70 per cent water and 30 to 40 per cent solid matter. The solid matter is dominantly calcium carbonate with a range of 50 to 70 per cent. The other constituents are silica, alumina, iron oxide, magnesium carbonate, and organic matter. The high content of insoluble matter in the sludge is correlated with white occupation of the region.

INTRODUCTION

Lake Monona is in the Four Lakes Region of southern Wisconsin and is the third of the chain, Lakes Kegonsa and Waubesa being first and second respectively and Lake Mendota fourth. In a previous paper the writer (1) described the physical and chemical characters of the bottom sediments of Lake Mendota, and in two subsequent papers Williams and McCoy (2) discussed the rôle of the micro-organisms in the bottom sediments in the precipitation of calcium carbonate and described the micro-flora of these sediments. This paper presents the results of studies of the bottom sediments of Lake Monona. It is assumed that the microbiological conditions in the bottom sediments of this lake are not unlike those in the bottom sediments of Lake Mendota.

A clam sampler was used to obtain samples of the sludge covering the bottom of Lake Monona and a sampler devised by the writer was employed to obtain cores of the sediments beneath the bottom sludge. The samples were collected by the writer with the assistance of H. Barton and G. T. Owen, the work being done in subzero weather during February, 1934. The determinations of water content were made by H. Barton, the preliminary work of preparation of the samples for analysis was done by H. Kundert, and the analytical work was done by the writer assisted by Philip Servais.

The study of the sediments of Lake Monona was supported by a grant from the funds of the Committee on Sedimentation of the Division of Geology and Geography of the National Research Council. The funds for the construction of the samplers for obtaining the samples were given some ten years ago by the National Academy of Science in a grant from the Bache Fund. This assistance is gratefully acknowledged.

DRAINAGE IN LAKE MONONA

It is probable that the greatest contribution to the waters of Lake Monona is from Lake Mendota. The

latter lake, in addition to many ephemeral small brooklets and springs, receives the inflow of two small streams. Pheasant Branch empties into it on the west end. This stream drains the basin of extinct glacial Lake Middleton and the western corner. This drains Lake Wingra, a small lake about a quarter of a mile west of Lake Monona. It now largely flows through an artificial channel that follows a somewhat circuitous course between the two lakes. Before the advent of the

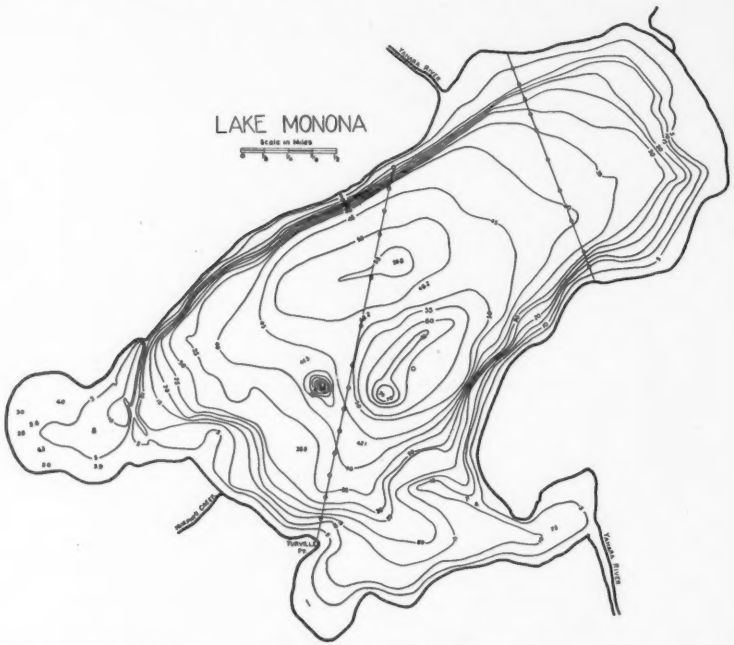

FIG. 1.—Map of Lake Monona. Shows depths, drainage, and positions of the traverses.

margining glacial deposits. Catfish River, draining the upland areas north of the lake, enters on the north side. Lake Mendota discharges on the east end across a narrow area into Lake Monona, the connection being known as the Yahara River. In addition to the Yahara River inflow, Lake Monona receives the waters of Murphy's Creek near the southwhite men the channel was more or less non-existent and the connection was through swamps. Starkweather Creek enters Lake Monona on the northeastern corner. Other drainage into the lake consists of small ephemeral brooklets and springs. In all cases the permanent streams entering Lakes Mendota and Monona pass through swamps before entrance and

these squamps before the advent of the white man in the region must have effectively screened out most of the sediments carried in suspension. This is still rather well done. All the lakes are in glacial basins dammed by morainal and associated deposits.

The bed rocks of the areas surrounding lakes Mendota, Wingra, and Monona consist of Cambrian dolomitic sandstones and dolomites which are overlain on some of the higher areas by Ordovician formations which from the base upward are the Oneota dolomite, St. Peter sandstone, and Platteville limestone. These strata are overlain by a variable thickness of glacial drift which in turn is veneered by a variable thickness of loess. The lake with its drainage and depths is shown in Fig. 1.

GENERAL CHARACTER OF THE BOTTOM SEDIMENTS OF LAKE MONONA

The bottom sediments margining the shores of Lake Monona are, in general, more or less muddy sands. These have been sampled only at the top as it has not been found possible to drive the core sampler into them. A few hundred feet from the shore the sediments pass into a black sludge at the top and into marls beneath, the latter generally termed mud. The sludge has the consistency of a thick soup and is black from contained organic matter. It has a thickness estimated to attain a maximum of perhaps 2 feet. It passes below into firmer sediments which have a gray color and at the lowest level penetrated are almost white. It is thought that the changes in color from the summit downward represent stages of diagenesis of which the sludge is the first.

SOURCES OF THE SEDIMENTS ON THE BOTTOM OF LAKE MONONA

Sediments attain Lake Monona in suspension and solution in the inflowing waters, through action of waves on the shores, and by way of the atmosphere. The content of dissolved constituents in the inflowing waters should be fairly large as they pass over and through rocks and soils that contain much carbonate of calcium and magnesium. It is probable that finely divided materials may be contributed in colloidal and visible suspension by the same waters, and this was probably the case to some degree even when the lake was surrounded by forest. It is not likely that material of coarse silt and large dimension enters through the permanent streams as these pass through swamps before entering the lake and before the advent of the white man in the region the quantity of coarse or muddy sediments entering the lake from the surrounding areas must have been nearly, if not zero. The shores at the present probably contribute considerable material of sand and smaller dimension and possibly some of large dimension, but in pre-white man days the quantity from this source was probably much less than now as the shores must have been

screened by bushes and trees and the shallow waters must have contained much fallen vegetation in the form of trunks and branches of trees. Since the clearing and cultivation of the areas around the lake there has been erosion of the cultivated lands with direct contributions of water with burdens of sediments from the lands to the lake, particularly during and after times of considerable rainfall when the runoff from the fields brings much muddy water directly to the lake. Another source of sediments that has obtained in Lake Monona for perhaps the past fifty years is that connected with the discharge of sewerage into the lake. However, nothing has been detected in the sediments that can be referred to this source.

Some sediments enter the lake by way of the atmosphere. Since the beginning of cultivation of land about the lake this probably has been a growing contribution, and the contribution may have been very large in the dry years when much dust was raised by winds. The dry weather of recent years and the extensive cultivation of the Great Plains areas may be considered to have been responsible for some contributions. No material of atmospheric deposition has been detected in the bottom sediments of Lake Monona, but this should not be expected as it is essentially impossible to differentiate fine material of this transportation from that brought by water.

No published or other analyses of the waters of Lake Monona are known to the writer, but as the larger part of the water in the lake seems to have been derived from Lake Mendota it would seem that the dissolved contents of the waters of Monona should be like those of Mendota. The waters of this lake have been analyzed many times. The mean of two analyses, the analyses having been made by E. B. Hall and C. Juday (3), is as follows.

	Parts per million
SiO_2	15.2
Al_2O_3, Fe_2O_3	2.2
Ca	19.8
Mg	21.6
Na	3.6
K	2.2
CO_3	77.2
SO_4	15.3
Cl	3.0
	160.1

The analyses indicate that the chief substances in solution are calcium and magnesium carbonates and silica, the last most likely in colloidal suspension. Twenty-four analyses of the waters of Lake Mendota, made of waters taken from different parts of the lake, from different depths, in different times of the year, and in different years from 1906 to 1910, give 32.7 parts per million of calcium, 25.2 parts per million of magnesium, and 8.7 parts per million of silica (3). It will be noticed that the ratio of the calcium to magnesium is about the ratio of these two elements in dolomite (32.7:24.47). This fact is in harmony with the sources from which the waters in large part obtained the contained dissolved matter, that is, the dolomitic sandstones and dolomites which form the hills surrounding the lakes and glacial

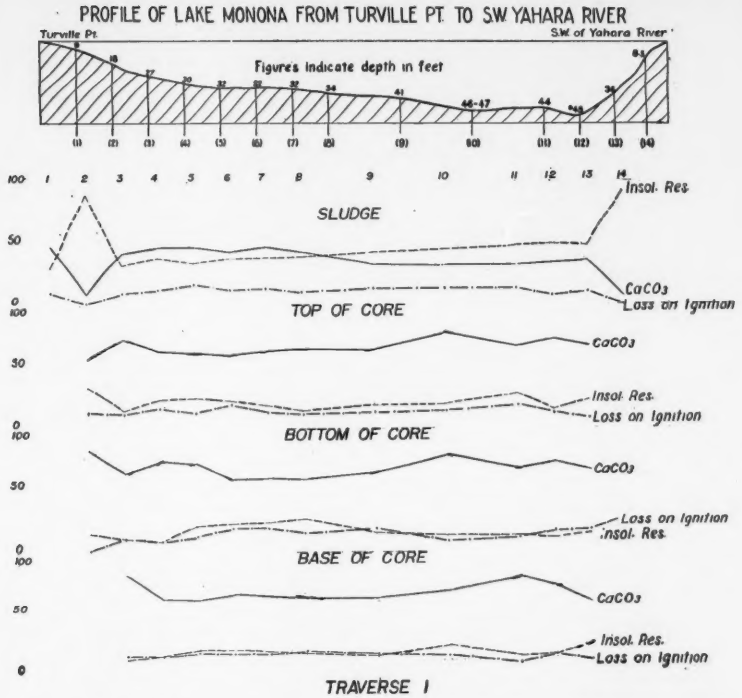

FIG. 2.—Profile of traverse 1. The graphs below give percentages of calcium carbonate, insoluble residue, and loss on ignition. The high content of insoluble residue in the sludge should be noted. It is thought that this rise in percentage correlates with the arrival of the white man in the region around the lake. It should also be noted that the curve of each constituent is regular and uniform over the main part of the transverse, but fluctuates greatly in the shallow water.

and loessial deposits that mantle these bed rocks.

Analyses of the sediments of Lake Monona have been made by Black (4).

COLLECTION AND ANALYSIS OF SAMPLES

Two traverses were made across the bottom of Lake Monona. These are shown in Figs. 2 and 3. One extends from Turville Point on the south shore to the north side of the lake a short distance southwest of the mouth of the Yahara River. Samples were taken on this traverse at fourteen stations, both sludge and core samples being obtained except at stations 2 and 14 where the bottom is composed of sand into which the core sampler could not be driven. In addition a sample was taken at a point about one-fourth mile east of station 8. This is near the deepest part of the lake and in the line of

the channel of the Yahara River in its passage across the lake. The stations were located 500 feet apart in the shallow waters and 1000 feet apart over the deeper parts of the lake.

Traverse 2 extends from a point on the north shore east of the Yahara River in a southeasterly direction to the south shore. Only clam samples were obtained on this traverse. The stations were placed at 500 feet apart in the shallow waters and 1000 feet apart in the deep waters.

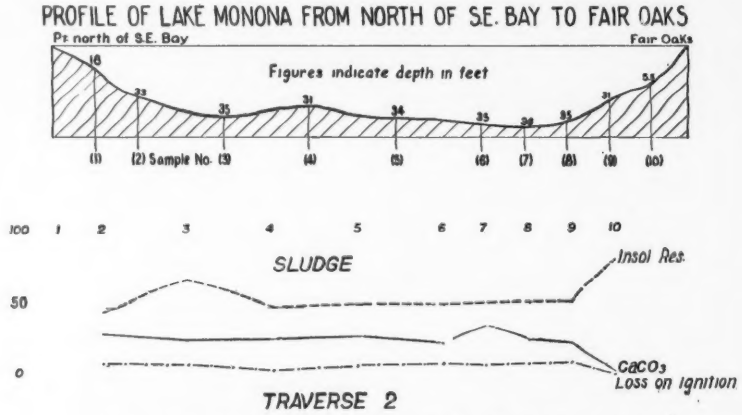

FIG. 3.—Profile and graphs of contents of sludge of traverse 2.

Samples for analyses were taken from three parts of each core. One sample was taken from the extreme lower end where contained in the point of the sampler. This is assumed to be the representative of the deepest sediments penetrated. Another sample was taken from the top of each core. This represents the top of the firm sediments. The third sample was taken from the bottom of the cylinder contained in the sampler. This represents an intermediate depth between the top and the bottom. Invariably the sampler was driven its entire length into the bottom sediments beneath the sludge, that is, to a depth exceeding 6 feet. The top sample represents the top of this 6 feet. As the cores obtained were never as long as the sampler it can not be positively stated that the other two samples are representative of the entire depth penetrated although it seems certain that a part of the base sample is from the depth of about 6 feet. The inability to obtain cores as long as the sampler arises from the fact that a core as it enters encounters increasing resistance as it rises in the inner tube or cylinder. The samples analyzed are designated sludge, top, bottom, base in order from the top downward.

The samples of traverse 1 were analyzed in the order given for cal-

cium carbonate, loss on ignition, and insoluble residue. The percentages for calcium carbonate given in these analyses also contain some of the soluble iron and aluminum, but the quantity can hardly be greater than 1 or 2 per cent. Many samples were analyzed, following standard procedure, for silica, iron, aluminum, calcium, and magnesium. These analyses are given on later pages.

CHEMICAL CHARACTER OF THE BOTTOM SEDIMENTS OF LAKE MONONA

The water content of the sediments in the cores ranges from a little less than 64 per cent to nearly 78 per cent. The lowest percentage, 63.92 per cent, was found in the core of station 2 of traverse 1. The highest was found in the core of station 12 with 77.89 per cent. The average water content of the cores was found to be about 70 per cent.

The calcium carbonate content of the sediments of traverse 1 (with which is included a small percentage of the aluminum and iron) ranges from 8 to 48 per cent in the sludge and 51 to 83 per cent in the cores. The highest percentage of calcium carbonate in the sludge was found at stations 4, 5, and 7 where it is about 48 per cent and the lowest at stations 2 and 14 where the percentages are 10 and 8 respectively. At each of these two stations the samples consist almost entirely of quartz sand and each station is close to the shore. The common percentage of calcium carbonate in the sludge ranges between 32 and 44.

The sediments below the sludge have a range in calcium carbonate (with which is included some iron and aluminum, both small) from 5.1 per cent in a sample from the top of station 15 to 83 per cent in a sample from the bottom of station 2. The common range is between 60 and 75 per cent with most of the percentages in the vicinity of 65. The magnesium estimated as MgO ranges from 0.47 to 2 per cent.

The loss on ignition (with CO_2 removed) ranges from 0 per cent at station 14 to 15 per cent at station 9 and the common range is in the vicinity of 12 to 14 per cent. The loss on ignition in the sludge samples is not greatly different from what it is in the samples from the sediments below the sludge. As the sludge is decidedly black due to the contained organic matter and the sediments below the sludge grow progressively lighter with depth it is inferred that the loss on ignition in the sludge sediments is due in part to the burning of the organic matter, whereas in the samples of sediments below the sludge the loss is thought to be largely due to the dehydration of the silica that composes much of the insoluble residue. Some must also have come from the dehydration of clay.

The highest percentage of insoluble residue was found in the sludge with 92 per cent in a sample collected at station 14. The insoluble residue is mainly silica. This is known to consist of small particles of quartz, tests of diatoms, and probably colloidal silica. Fifty-nine species of diatoms were identified in the muds of

the neighboring Lake Mendota and it seems probable that the same species dwell in Lake Monona. The insoluble residue in the sludge is greater than in the sediments below where the range is only from 11 per cent at several stations to 34 per cent at the top of station 2.

The iron in the samples analyzed, estimated as Fe_2O_3, is highest in the sludge samples and ranges from 2.7 per cent at station 9 to 3.2 per cent at station 12. The range in the firm sediments below the sludge is from 0.5 per cent at station 13 to 1.8 per cent at station 8. The average percentage in the sludge samples is about twice as great as in the sediments below the sludge. It is extremely probable that most of the iron in the sediments is in ferrous form as the carbonate. The aluminum, estimated as Al_2O_3, is also commonly higher in the sludge than in the sediments below the sludge, ranging from 1.8 per cent at station 8 to 8.4 per cent at station 11. The range in the cores is from 0.5 per cent at station 13 to 4.1 per cent at station 8. The percentage in most cases lies between 0.5 and 2 per cent. Evidently the sediments do not contain much clay. A graph of the contents of the sediments of traverse 1 are shown in Fig. 2.

Partly complete sets of analyses from several stations of traverse 1 are given on page 75.

The contents of the sludge of traverse 2 are shown in the graph of Fig. 3. The nearly similar contents of the sludge from the traverse is noteworthy. The only departure is found in the sample from station 10. This is near the shore on the south end of the traverse.

The analyses, profiles, and graphs of the percentages of the components of the sediments show that the calcium carbonate of the sediments below the sludge is greater than in the sludge, and, correspondingly, the sum of the insoluble residue and the ferric iron and the alumina in the sludge is greater than in the sediments below. The loss on ignition in the sludge is a little less than in the sediments below the sludge. To what are these various differences due?

It is inferred that the extrance of suspended sediments into Lake Monona has been greater since the appearance of white man in the Four Lakes region than before due to his clearing of the forests and cultivation of the lands making the acquirement of sediment thus much easier for both water and the atmosphere. It is suggested that much of the present sludge has accumulated during the 100 or so years of occupancy by the white man and that the greater percentage of insoluble residue and aluminum therein may be referred to human influence. It is considered probable that the contribution of wild-blown dust from far distant regions is now greater than in earlier years due to the cultivation of the western prairies in the past 20 to 25 years. In previous years the grass had protected these lands from wind erosion. The industry and burning of coal in the city of Madison may have made some contributions to the insoluble residues in the sludge and

STATION 4

	Sludge	Bottom	Base
SiO_2	25.0	7.1	8.5
Fe_2O_3	3.2	1.3	1.0
Al_2O_3	4.3	0.6	1.1
CaO	23.3	38.6	36.4
MgO	2.0	0.47	1.36
Loss on Ignition	36.8	48.8	48.1
Total	94.6	96.87	95.46

STATION 8

	Sludge	Top	Bottom
SiO_2	29.7	11.8	8.7
Fe_2O_3	2.9	1.8	0.69
Al_2O_3	1.8	1.1	4.1
CaO	20.9	34.0	27.5
MgO	2.0	1.3	1.3
Loss on ignition	34.8	46.7	43.7
Total	92.1	96.7	95.99

	STATION 10		STATION 13	
	Sludge	Bottom	Bottom	Base
SiO_2	33.9	8.8	10.4	19.3
Fe_2O_3	3.2	1.4	1.4	0.5
Al_2O_3	8.1	0.6	0.5	0.7
CaO	18.6	36.9	35.6	29.5
Loss on ignition	29.6	49.1	45.9	40.3
Total	93.4	96.8	93.8	90.3

RANDOM STATIONS

	2	5	9	11	12
	Top	Top	Sludge	Sludge	Sludge
SiO_2	48.5	17.5	30.9	36.1	37.4
Fe_2O_3	1.0	1.3	2.7	3.1	3.4
Al_2O_3	2.8	3.47	6.9	8.4	7.7
CaO	21.7	30.8	20.9	17.6	16.7
Loss on ignition	18.3	42.0	31.6	29.5	29.9
Total	92.3	95.07	93.0	94.7	95.1

soot may account for some of its blackness. However, little or nothing has been seen that might be referred to these sources, and the contributions therefrom are considered small.

The percentage of calcium carbonate in the sludge is smaller than in the sediments below the sludge. In addition to the relative increase in calcium carbonate due to elimination of organic matter there is the possibility of an absolute increase through precipitation of this salt in the sediments below the sludge from calcium carbonate in solution in the permeating waters. This possibility is considered on a later page.

The organic matter obviously decreases downward. This decrease is referred to decomposition by bacteria.

It will be noticed that the magnesium carbonate content of the sediments is very small. Obviously this salt is not precipitated to any great degree. This may perhaps be corre-

lated with greater solubility as compared to calcium carbonate and perhaps also to the selective use of calcium carbonate by organisms so far as these are responsible for the precipitation of the carbonates in the lake. The small percentage of magnesium carbonate in the sediments is the more remarkable because of its high percentage in the waters of the lake. Evidently factors other than the quantity of magnesium carbonate in solution are necessary for precipitation of this salt.

THE PRECIPITATION OF THE CALCIUM CARBONATE

The calcium carbonate in the sediments of Lake Monona, as in Lake Mendota, is mostly finely divided crystalline calcite which seems to be entirely devoid of traces of organic origin. Some samples contain a few shells, particularly those from the shore parts of the traverse, but most of the calcium carbonate is not composed of shells. How did this calcium carbonate attain precipitation? Some of it may have been precipitated due to escape of carbon dioxide when the waters are warmed in the summer time. Some seems certainly due to precipitation by small planktonic animals and plants, chiefly the latter. Calcium carbonate of inorganic precipitation and that precipitated by plants through extraction of carbon dioxide without any contact of the precipitated carbonate with the plants would be in the form of small crystals of calcite. Calcium carbonate thus precipitated in most cases must fall into sludge when it reaches the bottom.

Williams and McCoy (2) have shown that the sediments of Lake Mendota contain bacteria that consume organic matters and produce carbon dioxide that there bacteria are extremely abundant in the sludge. The carbon dioxide returns the previously precipitated calcium carbonate into solution in the waters permeating the sludge. They have shown that the sediments contain bacteria that precipitate calcium carbonate. These bacteria may be postulated to reprecipitate the calcium carbonate in solution in the permeating waters. While it has not been demonstrated that this is done in the sediments under the conditions prevailing on the bottom of Lake Mendota, it has been shown that it does take place under the conditions of the laboratory and it may be postulated to take place in Lake Mendota and similar lakes, among which is Lake Monona, but probably at a slower rate because of the lower temperature. It is also possible that these bacteria may precipitate more calcium carbonate from the permeating waters than had previously been acquired from the sludge and that this precipitation might continue as long as the permeating waters brought this salt in solution.

SUMMARY

The bottom sediments of Lake Monona consist of a black, organically-rich sludge underlain by light-colored firm sediments known as

marls or muds. The sludge consists of inorganic materials brought in suspension in the water or dropped from the air, organic matter thought to be largely derived from plants and animals living in the lake, organically and inorganically precipitated calcium and magnesium carbonates, and organic silica in the form of shells of diatoms of which fifty-nine species have been found in the bottom sediments of the nearby Lake Mendota.

The sludge has a content of calcium carbonate in or near the range from 30 to 45 per cent; in the underlying marls the range is between or near 50 to 70 per cent. The insoluble residue in the sludge is greater than in the underlying marls and is in or near the range from 35 to 50 per cent, whereas in the marls below it is in or near the range from 15 to 25 per cent.

The magnesium oxide content is small and in the vicinity of 1 to 2 per cent. The content of ferric and aluminum oxide is greater in the sludge than in the underlying marls. Both are small.

Bacteria destroy organic matter in the sediments and produce carbon dioxide. The carbon dioxide in the permeating waters return the calcium carbonate into solution. Other bacteria in the sediments are postulated to reprecipitate the calcium carbonate and it is thought that they may precipitate more than the quantity originally dissolved and thus produce an absolute increase in the quantity of this salt in the marls as compared to the sludge as the diagenetic change from sludge to marls takes place.

The *raw sediments*, the black sludge, would produce, if lithified in that form, a calcareous black shale; the cohesive sediments beneath the sludge would produce a siliceous-argillaceous limestone almost devoid of calcareous organic matter in spite of the fact that organisms are not rare over many parts of the lake.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 7, NO. 2, PP. 78–83. FIG. 1, TABLES 1-2,
AUGUST, 1937

HEAVY MINERALS IN ILLINOIS SANDS AND GRAVELS OF VARIOUS AGES*

J. E. LAMAR[1] AND R. E. GRIM[2]
Illinois State Geological Survey

ABSTRACT

Studies of the heavy minerals in 9 samples of Recent sand, 18 samples of Glacial sand, and 8 samples of Cretaceous sand reveal that the Glacial sands and the Recent lake and river sands derived from glacial deposits are characterized primarily by hornblende, pyroxenes, garnet and magnetite, usually in comparatively large amounts, with minor amounts of epidote, tourmaline, and zircon. Noteworthy also is the uniformity of the heavy mineral assemblages of the Pleistocene and Recent sands with reference to mineralogic composition and relative abundance of the different mineral grains. It suggests a similar ultimate source area for all these deposits. The suite of minerals indicates that igneous rocks were dominant in the source area.

The heavy mineral assemblages of the Cretaceous sands are very different from those of the Glacial sands or of the lake and river sands derived from Glacial deposits and are characterized primarily by kyanite, muscovite, tourmaline, zircon, staurolite, and rutile, with minor amounts of ilmenite, leucoxene, and sillimanite. The rare earth minerals, monazite and xenotime, although present only in small amounts, are consistently found in the Cretaceous sands and only very occasionally found in the non-Cretaceous sands. The source area for these sediments differed from the source of the Pleistocene and Recent sands. Metamorphic rocks such as schists and slates are indicated by the abundant stress minerals.

INTRODUCTION

It has lately been possible for the writers to separate and examine the heavy minerals of a large number of samples of Illinois sands in connection with a project conducted by the Illinois State Geological Survey. The resulting information, it is believed, will add to the general fund of knowledge regarding the heavy minerals in sands, particularly in Glacial sands and sands derived from glacial deposits. Analyses of many additional samples will be necessary before a detailed picture of the heavy mineral content of each sand horizon is available. However, the data at hand are considered sufficient to indicate the general character of the heavy minerals in many types of Illinois sands and to permit some conclusions concerning their distribution and the nature of the source rocks from which they were derived.

An added reason for presenting the information is the belief that the full significance of heavy minerals in sands cannot be interpreted until a large body of data on the heavy mineral content of diverse sands is accumulated.

The writers are indebted to Drs. M. M. Leighton and G. E. Ekblaw of the Survey staff for valuable advice regarding sites where deposits of the various origins and ages might

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[1] Geologist and Head of Non-Fuels Division, Illinois State Geological Survey.

[2] Petrographer, Illinois State Geological Survey.

be sampled, and to Mr. I. T. Schwade for his able assistance in the field and laboratory work.

PROCEDURE

Samples of 25 to 50 pounds were secured from outcrops except the samples of river sands, all but one of which were obtained from the stock piles of companies that dredge sand from bars in the river channels. Laboratory examination revealed that very few, if any, heavy minerals were coarser than a 20-mesh sieve and therefore all material retained on the 20-mesh sieve was discarded. The subsequent use of the term sand, therefore, herein refers to the minus 20-mesh fraction of the samples.

Two hundred grams of raw sand were washed to remove clay and silt and then treated with hydrochloric acid to remove carbonates and soluble iron compounds. The sand remaining was placed in a separatory funnel with bromoform and the heavy minerals were thus segregated. The weight of the heavy minerals was determined and correction was subsequently made for quartz, rock fragments, or other light mineral grains occurring with the heavy minerals, on the basis of estimates made with the petrographic microscope. The data regarding the percentage of heavy minerals are therefore only approximate and the fact that they are shown as a fraction of a per cent for some samples does not necessarily indicate a degree of accuracy of that order in determining quantities.

The minerals in each sample were identified with petrographic microscope using index of refraction liquids.

SOURCE OF SAMPLES

The location, nature, and age of the deposits from which the samples studied were obtained are given in Table 1. The locations of the samples are shown in Fig. 1.

RESULTS OF PETROGRAPHIC STUDY

The heavy minerals identified in the samples are listed in Table 2, together with estimates regarding their relative abundance.

CONCLUSIONS

Those minerals which are very rare and occur in only a few samples are

TABLE 1. *Identification and source of samples; amount of heavy minerals*

Sample No.	Age or Source of Sample	Amount of Heavy Minerals* Per Cent by weight	Character of sample	Thickness sampled—ft.	Location†	Remarks
			Recent River Sands			
275	Mississippi River	1.6	Sand		Near Alton	Dredged
279	Mississippi River	2.0	Sand		Near Gladstone	Dredged
284	Mississippi River	1.9	Sand		Near Hampton	Dredged
265	Ohio River	0.9	Sand		Near Golconda	Dredged
319	Ohio River	0.9	Sand		T15S R2E Sec. 18 NW NW SW	Beach of River
277	Illinois River		Sand		Near Beardstown	Dredged
334	Wabash River	1.5	Sand		Near Mt. Carmel	Dredged
			Beach of Lake Michigan			
353		1.4	Sand		T42N R13E Sec. 5 SW SW SW	
354		9.0	Sand		T44N R12E Sec. 9 SE SW SE	
			Beaches of Glacial Lake Chicago			
20	Glenwood Stage	2.1	Pebbly sand	5½	T42N R13E Sec. 33 Center	
242	Glenwood Stage	0.3	Pebbly sand	3	T35N R14E Sec 4 NE NW NW	
			Outwash Deposits—Wisconsin Age			
6	Lake Border	0.7	Gravel	8	T44N R11E Sec. 15 NW NW SW	
35	West Chicago	1.7	Gravel	23	T40N R8E Sec. 2 NW SE SW	
355	West Chicago	0.5	Gravel	17	T43N R8E Sec. 22 NW SE SW	
9	Valparaiso (?)	0.4	Gravel	20	T34N R9E Sec. 35 SE NW SE	
11	Cary sub-stage—Kankakee torrent deposit	1.2	Gravel	12	T33N R4E Sec. 9 SW NW NW	
335	Probably Cary sub-stage	1.2	Gravel	2	T13S R1W Sec. 27 NW NW SW	
357	Marseilles	1.0	Sand and gravel	13½	T34N R5E Sec. 18 SE NW NW	
248	Bloomington—Normal	0.8	Gravel	18	T16N R8E Sec. 21 SW SW SE	
257	Bloomington—Normal	1.8	Sand and gravel	18	T17N R7E Sec. 28 SE NE NW	
346	Probably Bloomington	1.0	Sand and gravel	28	T23N R7W Sec. 2 SW SE SW	
359	Shelbyville	0.5	Sand	11	T33N R5E Sec. 36 NW NW NW	
361	Shelbyville	0.5	Sand	3	T33N R5E Sec. 36 NW NW NW	
348	Tazewell sub-stage	0.6	Sand and gravel	25	T30N R3W Sec. 36 SE NW —	
350	Tazewell sub-stage	0.7	Sand and gravel	28	T15N R9E Sec. 15 SE NE NW	
			Outwash Deposits—Illinoian Age			
339		1.7	Sand	3	T7S R2W Sec. 16 NE NW SE	
341		0.7	Gravel	7½	T1N R1W Sec. 22 SE — —	
			Cretaceous Sands			
303		0.5	Sand	4	T15S R2E Sec. 2 NE NE SW	
304		0.7	Sand	12	T15S R2E Sec. 2 NE NE SW	
305		0.8	Sand	15	T15S R2E Sec. 2 NE NE SW	
306		0.4	Sand	13	T15S R2E Sec. 2 NE NE SW	
308		0.6	Sand	5½	T15S R1W Sec. 31 SE NE SW	
309		0.2	Sand	10	T15S R1W Sec. 31 SE NE SW	
313		0.5	Sand	3	T15S R1E Sec. 26 SW SW NE	
317		0.9	Sand	9	T15S R2E Sec. 18 NW NW SW	

* These percentages represent the amount of heavy minerals in all the material finer than 20 mesh (0.833 mm.).
† For county locations see Fig. 1.

TABLE 2. *Heavy minerals in Illinois sands and their relative abundance*

Sample No.	Age or Source of Sample	Actinolite	Andalusite	Augite	Biotite	Chlorite	Corundum	Diopside	Enstatite	Epidote	Garnet	Hornblende	Hypersthene	Ilmenite	Kyanite	Leucoxene	Magnetite	Monazite	Muscovite	Olivene	Pyrite	Rutile	Sillimanite	Staurolite	Titanite	Topaz	Tourmaline	Tremolite	Wallastonite	Xenotime	Zircon	Zoisite
	Recent River Sands																															
275	Mississippi River			C				C		C	A	A	C				C		R			R					R				C	
279	Mississippi River			C	R	A		C	R	C	C	A	R		VR		C	VR	C			VR	VR	VR			C		VR	VR	C	
284	Mississippi River.			C				C	R	C	C	A	C				A					R		R			R				C	
265	Ohio River			A		R		C		R	A	A	C	VR	VR	VR	R										R				VR	
319	Ohio River			R		C		R		R	A	VR	C	R	A	R	R	VR	C			C	R	C			C			VR	C	
277	Illinois River			C				C	VR	R	A	A	C		R		R										VR				VR	
334	Wabash River			R	R			R	R	R	A	R	R	VR	R	VR	VR					R		VR			VR				C	
	Beach of Lake Michigan																															
353				C				C		C	C	A	A				C			R		VR					VR					
354				A		R		A	R	C	C	C	A		VR		A					VR	•	VR		VR					VR	
	Beaches of Glacial Lake Chicago																															
20	Glenwood stage			R		C		R		C	C	A	C				C							R			C				C	
242	Glenwood stage			R		A	VR	R	VR	R	A	A	C				C					VR					R				R	
	Outwash Deposits—Wisconsin Age																															
6	Lake Border			C				C		R	R	A	C				C							VR			VR				C	
35	West Chicago	VR		C	R	C		R		R	VR	A	C				C					R		VR	R		R				R	
355	West Chicago			A				C		C	A	A	C				A	VR														
9	Valparaiso(?)			R		C		C		R	A	C	C		VR		A					VR		VR			VR				R	
11	Cary sub-stage			R				R		R	A	A	R		VR		R		R		VR	VR		VR			R				C	
335	Probably Cary sub-stage					C		R	R	R	A	A	R		R		R							R			C				R	
357	Marseilles			R				R	R	R	A	R	C				C			R							C				R	
248	Bloomington—Normal			R				R	R	R	C	A	C				R										R				C	
257	Bloomington—Normal			C		C		R	VR	R	C	C	R				VR					R					VR	C			R	
346	Probably Bloomington			C	R			R		C	A	A	C				R					R			R		C				C	
359	Shelbyville			R		C		C	VR	C	A	C	C				A			R		VR			VR		C					
361	Shelbyville			C	R	R		R		R	A	A	C				C										VR				VR	
348	Tazewell sub-stage			C				C	VR	VR	C	A	C				C							VR			R				C	
350	Tazewell sub-stage		VR	R	R			C		R	A	A	R				C									R	R				VR	
	Outwash Deposits—Illinoian Age																															
339				C				C	VR	C	A	A	C				C					VR			VR		R				C	
341				R	VR	C		R		C	A	A	R	VR		VR	A					VR					R				C	VR
	Cretaceous Sands																															
303										VR				C	A	C		VR	C			C	C	A			C			VR	A	
304										VR				C	A	R	VR	VR	A			C	R	C			C			VR	A	
305			VR							VR				R	A	R	VR	VR	A			C	R	A			C				A	
306										VR	VR	R		R	A	R	R		A			C	R	A			C			VR	A	
308														C	A	C	R	VR	A			C		C			A			VR	A	
309										VR				VR	C	VR	R	VR	A			C	VR	C			A			VR	A	
313														C	A	C	R	VR	C			C	R	C			A			VR	A	
317														C	A	C	VR	VR	A			C	R	C			A				A	

Explanation: A—Abundant, C—Common, R—Rare, VR—Very rare.

not thought to be of diagnostic significance because their discovery is mainly a matter of chance.

The Glacial sands and the Recent lake and river sands derived from glacial deposits are characterized primarily by hornblende, pyroxenes (augite, diopside, and hypersthene), garnet and magnetite, usually in comparatively large amounts, with minor amounts of epidote, tourmaline and zircon. The uniformity with reference to mineral composition and relative abundance of mineral species of the Pleistocene and Recent sands is noteworthy. It suggests a similar ultimate source area for all these deposits. The suite of minerals indicates that igneous rocks were predominant in the source area.

The heavy mineral assemblages of the Cretaceous sands are very different from those of the Glacial sands or those of the lake and river sands derived from Glacial deposits and are characterized primarily by kyanite, muscovite, tourmaline, zircon, staurolite, and rutile, with minor amounts of ilmenite, leucoxene and sillimanite. The rare earth minerals, monazite and xenotime, although present in small amounts are consistently present in the Cretaceous sands and only very occasionally present in the non-Cretaceous sands. A source area in which metamorphic rocks, such as schists and slates, were abundant is indicated for the Cretaceous sands by the abundant stress minerals.

The amount of black opaque grains noted in the Cretaceous, Pleistocene, and Recent sands appears to be about the same. However, in the Cretaceous sands the predominant black mineral is ilmenite showing some alteration to leucoxene, whereas in the other sands the dominant black opaque mineral is magnetite.

The mineral assemblage in the Pleistocene and Recent sands is generally more diverse than in the Cretaceous sands because of a greater variety of the rare or very rare constituents.

The zircon in the Pleistocene and Recent sands is dominantly colorless. In the Cretaceous sands purple grains are also prominent and many of the zircons exhibit very perfect zoning.

Sample 319, taken from the beach of Ohio River in an area where Cretaceous sands comprise the river bluffs, contains those minerals which characterize the Cretaceous sands and those typical of the Recent sands. Discounting this admixture the modern river sands and the modern Lake Michigan beach sands show no significant differences in their heavy mineral assemblages from the sands of Wisconsin age except for the presence of a small number of titanite grains in the latter. All of the river sand samples were taken at places well outside the outermost Wisconsin moraine. The main valleys of these rivers all contain Wisconsin outwash deposits which may have been the source of the river sands, thus accounting for the similarity of the heavy mineral assemblages. However, the tributary valleys of these rivers in the area outside the Wisconsin drift area are cutting at many

places in Illinoian drift whose heavy mineral assemblage should reflect itself in the river sands if it is noticeably different from that of the deposits of Wisconsin age. A sufficient number of Illinoian sands was not studied to indicate whether or not this is true but the two samples examined seem to suggest a similarity between the heavy mineral assemblages of the Wisconsin and Illinoian sands.

Although chlorite is a common alteration product of hornblende, the Glacial and Recent sands contain discrete grains of hornblende and chlorite with very few examples of hornblende showing any alteration whatsoever to chlorite. This suggests that the chlorite is an original constituent of the sand rather than a post-depositional alteration product of this ferro-magnesian mineral.

The hornblende in the Glacial and Recent sands is the common green variety.

All of the garnet grains in the Glacial and Recent sands are colorless or pink, and are probably of the grossularite or almandine varieties. In each sample in which the mineral is abundant a few grains can be found which show an "etched" appearance.

In the Pleistocene and Recent sands, minerals of the pyroxene group as a unit and hornblende are about equally abundant. The grains of diopside are unaltered. A few of the hypersthene grains and most of the enstatite and augite grains show the presence of a small amount of gray or yellow alteration product. Hypersthene, enstatite, and augite are considered as only moderately resistant[3] to weathering. The samples of Wisconsin age containing the minerals were obtained from outcrops above drainage level and of such topographic position as to be subjected to normal weathering processes. It may be concluded on the basis of the present study that diopside is more resistant to weathering than hypersthene, augite, or enstatite, and that the interval since their deposition in Pleistocene time has been sufficient to permit slight alteration of these minerals. Practically all the grains of these minerals exhibit about the same degree of alteration which is interpreted to mean that the alteration has occurred during the present cycle of sedimentation.

In the samples studied enstatite is more common in the early Wisconsin sands than in the middle Wisconsin sands; kyanite occurs in the middle Wisconsin sands but not in the early Wisconsin sands; olivine is present in the early Wisconsin but not in the middle Wisconsin sands; and kyanite, monazite, olivine, and staurolite occur in the Wisconsin outwash sands but not in the Illinoian outwash sands. Many additional samples must be studied before it can be assumed that these statements apply generally.

[3] Milner, H. B., Sedimentary Petrography, p. 437 London (1929).

REVIEWS

STRØM, KAARE MÜNSTER, *Land-locked waters, hydrography and bottom deposits in badly-ventilated Norwegian fjords with remarks upon sedimentation under anaërobic conditions*, Skrifter urgit av Det Norske Videnkaps-Akademi i Oslo. I. Mat.-Naturv. Klasse, No. 7, pp. 1–85, 1936.

A study of thirty Norwegian fjords and Den Norske Rende (Norwegian channel), partially land-locked basins, was undertaken to determine (1) the hydrographical conditions necessary for stagnation and the mechanism of ventilation; (2) the genesis of deposits under anaërobic conditions and their registration of change in hydrographic conditions in late Quaternary time; and (3) to draw a parallelism with ancient deposits as a result of principles developed in this study.

The hydrography and meteorology of the investigated area are reviewed. While the salinities of the surface waters are always low and variable, the bottom salinities are very constant—near that of the open sea. Surface temperatures are likewise variable while bottom temperatures are less changeable, though some differences between different fjords were noted. The bottom temperatures tend to rise with time and ultimately this leads to lowering of density so that partial or complete ventilation may take place. In most fjords the oxygen decreases with depth and in some falls to zero in which cases H_2S appears in notable quantities. The pH content also reflects the ventilation of the water-body and falls below 7.2 in waters with H_2S and is above 7.26 in the oxygenated waters. Phosphate is highest in the two most stagnated fjords where it is many times higher than in the open sea. No phosphate-bearing sediments, however, were noted.

Periodical changes are also described. Apparently partial or complete ventilation has taken place at several times in the different fjords. When the surface waters are cooled and contain little fresh-water, as in the spring, and strong off-shore winds carry away these waters, there is an influx along the bottom of ventilated salt water. The stagnant waters containing H_2S are lifted to the surface and oxidized at the same time with destructive effect on the fjord fauna.

The degree of stagnation is reduced by strong tides, is affected by the absolute depth of the threshold as well as relative depth of threshold and basin, and is materially affected by the basin shape. A supply of light fresh water to seal off the stagnant salt waters is of course essential.

Of most interest to sedimentologists is the chapter on bottom deposits. The physical appearance and organic content of each sample are briefly described and a few chemical analyses of P_2O_5 and organic carbon are given. In general the amount of organic matter, which formed the putrid loose deposits, varied with the degree of stagnation. In all cases the deeper parts of the sediments, as shown by core samples, contained more mineral substance than the uppermost.

Owing to the rising of the coast Strøm believes the fjords must have been at one time well-ventilated salt water basins. The black muds are therefore believed to be the sediments of the last or poorly aërated period, whereas the underlying more normal clays and sands are the record of the ventilated stage. In the Drammensfjord regular laminations, believed to be annual, were counted. These laminations of clay and black mud, which date back as far as the year 1300, rest on compact clay. This break in sedimentation is interpreted as a record of climatic change about 1300 and is confirmed by independent work on pollens.

The last section deals with the literature of land-locked waters and anaërobic sedimentation together with parallels from previous geological epochs. Valuable references and a good discussion of the problem of the black shales are given. Noteworthy is Strøm's belief that under some conditions the oceans themselves may have stagnated bottom waters. Bibliography, hydrographic charts, bottom profiles, sedimentation profiles and aërial photographs complete the report.

F. J. PETTIJOHN

University of Chicago

HAGERMAN, TOR H., *Investigaciones sobre el material clástico en formaciones del Norte Argentino*, Boletin Informaciones Petroleras, Año XIII, No. 139, 75–120, 1936. (Buenos Aires)

It should be stated at the outset that English versions, by the same author, of essentially the same work as reviewed here can be found in 1. Some lithological methods for determination of stratigraphic horizons, Proc. World Petr. Congress, London, 1933, vol. I, pp. 257–259, and in 2. Granulometric studies in northern Argentine, with a short chapter on the regional geology of central South America, Geografiska Annaler (Stockholm), 18, 125–213, 1936. The first presents only a bare outline of the methods; the second is fuller than the article under review, and gives much more about the regional geology of northern Argentina. However, it is neither so concise, nor at times so clear as the Spanish version.

In the work to be reviewed, Hagerman has attempted to use the physical characteristics of the grains or particles of sediments in stratigraphic correlation. To the same end, many workers have employed the variation in grain size as a function of stratigraphic distance (or a function of some other measurement made in the field), and the author has used modifications of this method. In addition he has introduced (previously) a new statistic, the "relative wideness" (ancho relativo) of grains, which can be used in testing the lithologic similarity of the same or different horizons. His points follow:

The most important things to study in clastic sediments are the quartz grains, since they often make up almost 100% of the sediment. The two most important things about the quartz grains are a. their size, which is directly related to their weight, and b. their cross-section perpendicular to the direction of movement of the current which transported them. Of these two elements, the size is easier to determine, but it does not yield so much information of correlative value.

Sieving determines size according to an intermediate dimension. Since the maximum dimension is a more important one, sieving does not yield fundamental data. It is necessary to make slides and to measure the major dimension on 200 to 300 grains to get a reliable value. From these measurements one gets (for a number of samples) a curve representing the variation of size of a. grains of maximum size, of b. the grains occurring with maximum frequency, and of c. the grains of minimum size. Hagerman plots only the first two series of values. He tries to make the second more useful by estimating the scatter about the mean, plotting really for this series two more or less parallel curves which he considers to outline the region of maximum frequency. In all this plotting, one ordinate is grain size and the other is stratigraphic distance or some similar measurement. In general the author finds that there is a sort of rhythmic variation or "swing" to the curves. Part of this rhythm corresponds to graded bedding; other regular variations may arise in a number of other ways. A sharp break in the grain-size curves often yields evidence for unconformities or faulting.

Of more theoretical and practical interest is the cross-section of the grains in question. The most significant information about any one grain would be the dimensions of the two sides of the rectangle of minimum area in which the grain could be inscribed. This information can be approximated simply by measuring the long dimension and that at right angles to it. The ratio of the smaller ("b") to the larger ("l") is called the relative wideness (ancho relativo). To use this value, for any one sample b/l is plotted as ordinate, and the maximum dimension (l) as abscissa on 1/10 mm. squared paper. Since b/l is always less than one, the ordinate is never greater than that value; the abscissa is limited solely by the size of grains dealt with. Any one sample will be represented on the diagram by a collection of points, each of which stands for one grain. If the points lie in the upper left part of the diagram, it indicates that the grains of that sample are small and more or less equant; if in the lower left, small and elongate. Points to the right, in similar way, indicate equant or elongate larger grains. If a number of samples be taken in some regular way, the points representing their relative wideness (b/l) may show some significant grouping or configuration. The crucial matter is, of course, that configurations from the

same bed or horizon would be expected to be similar, and that, conversely, similar configurations may be used, as are fossils, heavy minerals or grain size, to determine horizons.

The details of procedure are: collection of ½ cc. samples not more than 20 m. apart stratigraphically; mounting in Canada balsam; heating and moving about to get maximum dimension of grains parallel to slide; placing of cover-glass; measurements of maximum dimension and that at right angles, using 50–100 times magnification. For marking out the field of distribution, a search is first made for the most unusual grains, which are plotted with a big dot. Not many of these large dots, joined by a heavy line, are required to mark out the field. The interior is filled in with the number of points or dots thought necessary. (For qualitative work the distribution is more or less estimated.)

Following this part of the work is an outline of the geology of northern Argentina, and a description of the application of the above methods to study of the rocks of that area. When Hagerman started working there, the boundaries between most of the formations were unknown. After some work with grain sizes he came to suspect certain horizons, notable where breaks in the curves of distribution occurred. Plotting the fields of relative width bore out the grain-size work,—it was found that definite distributions corresponded to definite horizons or formations. Plates of these diagrams and curves are given for each of the stratigraphic units discussed, together with geologic maps and sections.

In the third section—that of conclusions and theory—Hagerman seeks to explain the different configurations of points representing different average "relative widths" of samples from different beds or formations. The fundamental idea is that there were more or less synchronous similar variations in (river) currents over considerable areas. Any one variation would give a plane of rock of similar lithologic character (with respect to grain-size and relative width), though identity in this character from place to place is not assumed. Such a plane, which is almost if not exactly parallel to the time planes in a sediment, is called a "granulometric surface."

The shapes of the different configurations are explained in such a detailed and condensed manner that anything short of direct quotation would be unsatisfactory. Hagerman treats of the action of turbulent currents, of varying currents, and of recurrent erosion of sediments already deposited. Each action or condition limits the types of grains which will be deposited at any one time, so that the diagram shows a definite and sharply limited configuration. Since the variations are regional in extent (for the non-marine sediments treated by the author), each granulometric surface will give similar configurations over wide areas, but through a restricted vertical thickness. The use of such information is obvious.

To the reviewer's mind, Hagerman has contributed one more important paper tending to bear out the thesis that lithologic characters may, even in a minute way, be similar over wide areas, and that studies of the physical properties of grains may be more important than mineralogic (heavy mineral) investigations. However, both lines of investigation should be followed in this thorough sort of way before any evaluation of the relative worth of the two methods is possible.

LINCOLN DRYDEN
Bryn Mawr College

Vulkane und ihre Tätigkeit—A. Rittmann, University of Basel, Stuttgart, pp. 1–179, 1936.

This is an excellent book on volcanoes, volcanic activity, and their associated phenomena. It offers little, however, of a direct sort to the sedimentationist. It does develop a splendid background for the interpretation of those sediments which owe a part or all of their characteristics to volcanic activity. Throughout, Dr. Rittmann has maintained a strictly practical point of view, although he has not neglected the theoretical aspects of the subject. Petrographic observations and interpretations are the prime purpose.

Volcanism is defined broadly to cover in addition to processes all rocks including derived sediments which result from this general activity. He even carries this so far as to state that the non-volcanic sediments play a subordinate role,—a statement with which others will not readily agree. A possible difference in

European and American thought is indicated by the acceptance of the early earth as a fluid mass.

The first section of the book deals with volcanic manifestations as we see them in active regions today, including fumaroles, geysers, lava seas and submarine eruptions. Ample reference is made to illustrative examples with excellent photographs to support the text.

The second section deals with the immediate products of volcanism, including a page on the pyroclastic sediments. This brief treatment makes no pretense to a complete discussion of these sediments and deals mainly in generalities. It is to be regretted that the pyroclastics are not dealt with more fully, since they so often give the best horizon markers in a volcanic series, especially in the pre-Huronian of the pre-Cambrian. Seven pages are given to a discussion of the detailed mineralogy and petrography of other volcanic rocks.

The following section discusses in some detail the construction of volcanoes.

Sixty pages are devoted to a discussion of the physical chemistry of magmas. This brief discussion covers Dr. Rittmann's views on differentiation, assimilation, petrographic provinces, and the role of gases in magmas. He brings out the relationship of gas pressure to crystallization and to eruption. This in the reviewer's opinion is one of the best contributions of the book.

The balance of this book takes up a classification of volcanos from different viewpoints, their distribution on the earth, and closes with a few comments on the role of volcanism in mountain building.

For the purposes of the sedimentationist, there remains still the need for a competent discussion of the role of volcanism in sedimentation. This need is perhaps felt more keenly by the pre-Cambrian geologist than by others, but by no means only by him. The extensive post-Cambrian volcanic activity of the North American west and the intercalated sediments amply illustrate this point. Dr. Rittmann's book, though an excellent contribution to our knowledge of volcanism, does not bridge this gap between these two geologic fields of study.

R. C. EMMONS
University of Wisconsin

CORRENS, CARL W., *Die Sedimente des Äquatorialen Atlantischen Ozeans. A. Die Verfahren der Gewinnung und Untersuchung der Sedimente*, Wissenschaftliche Ergebnisse der Deutschen Atlantischen Expedition auf dem Forschungs- und Vermessungsschiff "Meteor" 1925–1927, Band III —Dritter Teil, Verlag von Walter de Gruyter & Co., Berlin und Leipzig, 1935.

In this work Correns describes the apparatus by means of which samples from the equatorial Atlantic ocean were obtained. The apparatus consisted of a modified Ekman sampler by which core samples up to 95 cm. in length were obtained with the average around 50 cm., and a grab sampler of the Léger type.

The samples were studied both on board the "Meteor" and in the home laboratory. Methods for preparation of the samples for study and shipment to the home laboratory are described. Studies include determination of grain size and distribution, and research was made respecting influence of drying on grain size distribution. Microscopic studies were conducted for determination of mineral content of the samples, both light and heavy suites being considered. Studies of the very fine sediments are described. Various methods were used, among which were chemical analyses, staining, and x-ray. Determinations of composition by chemical methods include calcium carbonate, organic matter, manganese, phosphorus, iron, water content and hydrogen iron concentration. The last topic considered in the paper deals with ultramicroscopic research of the colloidal inorganic contents of the sea water. The original determinations of Murray and Irvine are given but Correns gives no results derived from his own studies.

The paper is of great interest to sedimentationists as it gives results of importance and, in particular, points out various methods of attack for determination of the characteristics of very fine sediments. The paper should be read by all interested in marine sediments.

W. H. TWENHOFEL
University of Wisconsin

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